

Inter-professional assessment of Posterior Tibial Tendon
Dysfunction and its timely diagnosis.

Durrant. B

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Inter-professional assessment of Posterior Tibial Tendon
Dysfunction and its timely diagnosis.

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Abstract

Posterior tibial tendon dysfunction (PTTD) is a progressive deformity which can result in the development of a pathological flat foot deformity. A mixed methods approach has been adopted for this study. This blended philosophical stance has embodied both inductive and deductive paradigms to provide a robust exploration, not possible when adopting just one approach.

The results presented within this thesis clearly demonstrates that there is inconsistency in the way in which clinicians practise when it comes to the assessment and diagnosis of PTTD. The tests that clinicians select for inclusion in the assessment of PTTD is problematic and differ significantly both within and across different professional groups.

The results provide a unique insight into the approaches to assessment and diagnosis among podiatry and physiotherapy advanced musculoskeletal practitioners. Following quantitative data acquisition and investigation of some of the most popularised clinical tests referred to by clinicians and highlighted as important during the content and thematic analysis sections, a novel contribution to this research foci is provided.

Findings clearly illustrate a lack of standardisation of the assessment and diagnosis of PTTD and with aligning evidence and research findings to clinical practice. The quantitative investigation and results have shown that reliance on these clinical tests in providing worthwhile and informative clinical information to aid in the assessment and diagnosis of PTTD is lacking. Navicular drift and navicular drop have been investigated and found not to be significantly different to a non-PTTD population. The single heel rise test, often used in a diagnostic capacity for PTTD, has been investigated and the results are not statistically dissimilar between PTTD and control participants.

Overall the results of this study confirm that PTTD receives a varied response to identification, assessment and diagnosis from specialist practitioners. Furthermore some of the tests confirmed by qualitative inquiry as being important to clinicians in the assessment process should not be relied on to differentiate pathology from non-pathological.

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Glossary

Baseline	A control measurement carried out before an experimental measurement.
Classification	Ordering of related phenomena into categories, groups, or systems according to characteristics or attributes.
Confounding Variable	An unforeseen, and unaccounted-for variable that jeopardises reliability and validity of an experiment's outcome.
Deductive	A form of reasoning in which conclusions are formulated about particulars from general or universal premises.
Inductive	A form of reasoning in which a generalized conclusion is formulated from particular instances or a collection of theoretical data.
Interpretivist	<p>Findings or knowledge claims are created as an investigation proceeds.</p> <p>All interpretations are based in a particular moment. That is, they are located in a particular context or situation and time. They are open to re-interpretation and negotiation through conversation.</p>
Mixed-Methods	A research approach that uses two or more methods from both the quantitative and qualitative research categories are used. It is also referred to as blended methods, combined methods, or methodological triangulation.
Navicular displacement	The difference in position of the navicular on either the X, Y or Z axis relative to a defined start position.
Navicular Drift	Difference in the position of the navicular relative to a defined start position on the positive Y axis.
Navicular Drop	Difference in the position of the navicular relative to a defined start position on the negative Z axis.
Positivism	A doctrine in the philosophy of science,

positivism argues that science can only deal with observable entities known directly to experience. The positivist aims to construct general laws, or theories, which express relationships between phenomena. Observation and experiment is used to show whether the phenomena fit the theory.

Right hand coordinate system

A system used to define the orientation and direction of the positive X, Y and Z axis.

Triangulation

A multi-method or pluralistic approach, using different methods in order to focus on the research topic from different viewpoints and to produce a multi-faceted set of data. Also used to check the validity of findings from any one method.

Chapter 1: Introduction

1.1 Background to the thesis

Posterior tibial tendon dysfunction (PTTD) is a disabling pathological flat foot condition, and can lead to significant restrictions to activities of daily living, bringing pain and limitation to the lives of those who receive a positive diagnosis. Although reported to be a reasonably common occurrence in the adult population, there are significant questions and challenges which affect the timely assessment and diagnosis of the condition by health care professionals’.

Although a plethora of new material relating to this topic has been published within the last decade, much of the research has explored assessment of the condition from the perspectives of understanding clinical characteristics, the changes during progression, and the benefit of intervention. This has led to a much healthier evidence base for the treatment of PTTD. However, despite this, diagnosis remains uncomfortably poor, and at best patients receive a delayed diagnosis and at worst a missed diagnosis.

Whilst evidence for successful intervention is available, it should be possible to identify the reasons for delayed and missed diagnoses. Investigation of interventions currently provides robust evidence for the treatment of the condition once diagnosed, however it does not provide any new information or help to explain why it is poorly diagnosed in the first place.

There has never been an investigation that has involved establishing, exploring, and debating the opinions and beliefs of the health care professionals (HCPs) who assess and treat patients with this condition on a frequent and regular basis. Nor have there been investigations that have blended the outcome of such research with quantitative investigation in order to establish a greater understanding of the preferred assessment methods’ of PTTD. Furthermore, some of the commonly employed tests currently used in assessment of this condition have not been investigated in a structured manner. An investigation of this kind would help to confirm the efficacy of current assessment methods, which would ultimately improve the diagnosis of this disabling foot condition.

Therefore, this study sought to bring together expert opinion through qualitative inductive enquiry, and use the results of this method of investigation to inform the second stage of the study. The second stage utilised quantitative deductive methods to examine some of the most commonly cited tests and assessment methods, in order to

provide new information that can be used to formulate a fresh approach to the assessment and diagnosis of the condition.

The thesis is presented in 10 chapters and the scope, aims, and objectives of the work are detailed in Section 1.2 and 1.3. Methodologically, the study utilises a mixed methods approach. That is to say that both quantitative and qualitative approaches have been adopted in order to achieve a full, thorough and comprehensive in-depth analysis of the topic. The detail surrounding the chosen methodology is further explained in Chapter 3. For each of the data chapters the methods are described within. Each data chapter has a discussion section. Although the various 'arms' of this study were conducted discretely, each discussion section will link the various studies demonstrating how each chapter builds on the previous one. A final summary discussion highlights the key points from each of the data chapters. As a consequence of the structure of this document there may be some overlap between the content in Chapter 2, and of that reported in Chapters 4, 5 and 6.

1.2 Scope of the investigation

The contribution that interdisciplinary working and collaboration makes to the assessment of PTTD and its timely diagnosis is unknown. This study sought to explore the opinions and beliefs of health professionals with regard to this topic in order to realise the impact on the poor diagnostic profile that is the status quo. This was achieved by the development and deployment of a questionnaire designed to explore the opinions and beliefs of extended scope musculoskeletal practitioners who frequently come into contact with the condition. The responses to this were further explored in a focus group setting.

Additionally, the investigation sought to facilitate quantitative data exploration. The quantitative studies presented herein were informed and shaped by the results of the qualitative results derived from the qualitative arm of the study. The approach uses a sequential mixed methods study design, the first of its kind into PTTD investigation.

It is commonplace in clinical practice to use a variety of methods to inform clinical reasoning and decision making. The assessment and diagnosis of PTTD is no exception. The single heel rise test and navicular displacement are two such clinical assessment methods that have a historical place in the minds of health professionals when assessing

this condition. These tests formed the basis of the quantitative data collection arm of this study.

The literature surrounding the efficacy of these tests is sparse. In fact, the navicular drift and drop test has never been investigated in this patient population. The quantitative part of this study sought to further the understanding of the interpretation and efficacy of both of these tests in the assessment and diagnosis of PTTD. This part of the study focussed on acquiring kinematic and kinetic data in patients diagnosed with PTTD and compared the results to control participants.

A lack of agreement about what constitutes the calcaneonavicular ligament (CNL) and its anatomical function led to further investigation of this ligament. In recent years, debate has surrounded the contribution of the CNL to the progression of PTTD. Additionally, the anatomical make-up of the CNL has been questioned.

The advent of ever more powerful magnets presented opportunities to investigate the positive aspects of improved resolution, and also, whether better resolution enables more complex structures, like the three bands of the CNL, to be studied.

The final section of this thesis pulls together both elements of the mixed methods approach and provides a rationale and a proposed structure for the future development of clinical protocols for the assessment and diagnosis of PTTD.

1.3 Aims and objectives of the study

The following aims were adopted in the construction of the study design.

1. Utilise the expert opinion of health care professionals to evidence the current approaches to assessment and diagnosis of PTTD.
2. Justify the need for evidence informed clinical protocol development in the assessment and diagnosis of PTTD.

The following objectives describe the boundaries of the work.

1. To explore the views and opinions of health care professionals who encounter PTTD in their clinical practice in order to explore levels of agreement in the areas of assessment and diagnosis.

2. To identify the frequency of identification of the three bands of the CNL using a standard foot and ankle protocol.
3. To determine the conspicuity of each part of the spring ligament on conventional, previously imaged foot and ankle MRI sequences, on a 1.5 or a 3 tesla magnet.
4. To investigate static and dynamic navicular displacement around the mediolateral (Y axis) providing data on transverse plane displacement and the vertical (Z axis) providing data on sagittal plane displacement.
5. To investigate maximal heel height and frontal plane rearfoot angle during a single heel rise test and during the stance phase of gait in participants with PTTD and compare with controls.
6. To investigate the relationship between navicular drift (NDri) and navicular drop (NDro) during a single heel rise manoeuvre.
7. To blend the findings of the qualitative and quantitative data analysis and interpretation in order to make recommendations for future clinical protocol development.

1.4 Research questions

The aims and objectives of this study were met by addressing 3 principal research questions as follows:

1. What contribution does interdisciplinary consultation make to the exploration of assessment approaches for PTTD with a view to clinical protocol development?
2. Is there a disconnect between interdisciplinary opinions and beliefs surrounding the assessment and timely diagnosis of PTTD?
3. Do the kinematic and kinetic changes associated with clinical assessment tests for PTTD reflect interdisciplinary opinions and beliefs identified through qualitative exploration of questionnaire and focus group discussion data?

1.5 Ethical approval

Ethical approval was obtained from the NHS research ethics committee (ref no: 11WM/0034) and Staffordshire University research ethics committee prior to the study commencing. Informed consent was incorporated within the design of the online questionnaire, and all participants were required to consent prior to moving onto the questions. For the quantitative data collection, participants were required to give informed consent prior to any data being collected. Participants were sent the participant information sheet prior to attending for their data collection appointment. Details of the ethical approval, consent forms and participant information sheets can be found in Appendices 12.4, 12.5 and 12.6 and 12.10. The research passport issued by the collaborating Trust can be found in Appendix 12.7 and the R&D approval in Appendix 12.8.

Chapter 2: Review of the literature

Aspects of this chapter have been published

Durrant, B., Chockalingam, N., & Hashmi, F. (2011). Posterior tibial tendon dysfunction: a review. *J Am Podiatr Med Assoc*, 101(2), 176-186.

Durrant B., Chockalingam N., Richards P.J., and Morriss-Roberts C. Posterior Tibial Tendon Dysfunction: What does the Single Heel Raise Test mean in Assessment? *Foot and Ankle Online Journal*. 2015, 8 (2): 6.

2.1 Introduction

The posterior tibial (PT) muscle is situated within the deep posterior compartment of the leg. In normal function it influences the function of the subtalar (ST) and midtarsal (MT) joints during gait, providing an inversion moment at the subtalar joint (Funk, Cass, & Johnson, 1986; Mueller, 1991). PTTD is a common cause of pathological flat foot deformity in adults (Weinraub & Saraiya, 2002), which when left untreated can lead to considerable functional impairment, consequently having a detrimental effect on the quality of life of the individual involved. Although there are numerous publications that have studied the effects of clinical interventions at specific stages of progression of PTTD (Houck, Nomides, Neville, & Samuel Flemister, 2008; Kohls-Gatzoulis, Angel, et al., 2004b; Kulig et al., 2005; Kulig et al., 2006; Kulig et al., 2009; Neville, Flemister, & Houck, 2009, 2010), there is still uncertainty regarding the clinical identification and subsequent diagnosis of the condition in the foot.

It is clear that more information regarding the assessment, diagnosis and progression of PTTD is required in order to ensure that timely and appropriate interventions are used, not only to alleviate the cost burden to the National Health Service (NHS) but also to prevent deterioration in the quality of life of the individuals involved. Many of the publications related to PTTD report on conservative or surgical interventions, or on the outcome data of conservative interventions or surgical procedures (Jahss, 1982; Johnson & Strom, 1989; C. Neville, A. S. Flemister, & J. Houck, 2013; Vulcano, Deland, & Ellis, 2013; Wainwright, Kelly, Glew, Mitchelmore, & Winson, 1996). These data, although valuable, inform clinicians of the benefit of specific interventions, and given that many intervention studies have attempted to recruit early stage PTTD, this assumes that patients receive a timely diagnosis.

There is clear evidence to suggest that PTTD significantly affects patients' quality of life. Evidence also indicates that early conservative intervention can greatly improve quality of life with regard to disability, function and pain (Kulig et al., 2009). This would indicate that sizeable cost reductions could be made by increasing awareness of the condition which would improve early diagnosis.

2.2 Structure and function of the PT tendon

The PT muscle originates from the posterior aspect of the interosseous membrane and from the superior two thirds of the medial part of the posterior aspect of the fibula (Semple, Murley, Woodburn, & Turner, 2009). It also takes part origin from the superior aspect of the posterior tibia and the intermuscular septa of the adjacent muscles of the posterior compartment. Many studies have confirmed its function predominantly occurs during the stance phase (Basmajian & Stecko, 1963; Mosier, Pomeroy, & Manoli, 1999; Murley, Buldt, Trump, & Wickham, 2009)

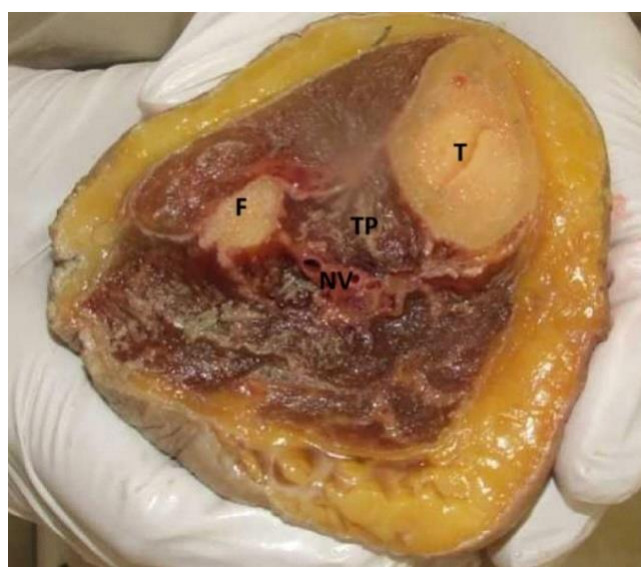
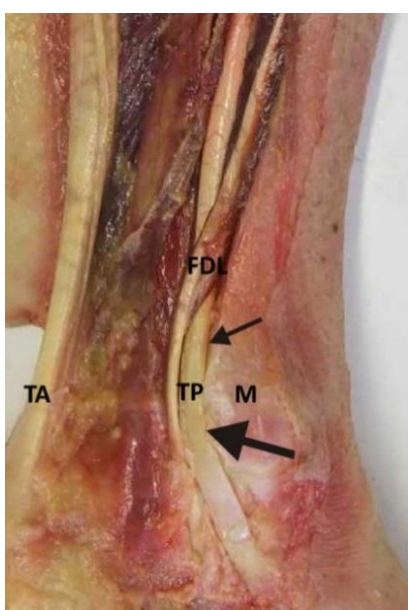


Figure 1: Anatomy of posterior tibial tendon.¹ Figure 2: The anatomy and location of the posterior tibial muscle belly.

Due to its orientation with both the subtalar and the ankle joint axis, the posterior tibial muscle is both a plantar flexor at the ankle joint and an invertor of the foot at the subtalar joint, and is therefore known as a main supinator of the foot during stance (Basmajian & Stecko, 1963; Funk et al., 1986; Mueller, 1991; Murley et al., 2009).

2.3 Epidemiology and prevalence of PTTD

There is little information relating to the epidemiological features of PTTD, however what is available suggests that middle aged women and older people are the most commonly

¹ Both these images were reproduced from Semple, R., Murley, G., Woodburn, J., & Turner, D. (2009). Tibialis posterior in health and disease: a review of structure and function with specific reference to electromyographic studies. *Journal of Foot and Ankle Research*, 2(1), 24.

affected (Fenn & Chiodo, 2006; Holmes & Mann, 1992; Johnson & Strom, 1989; Pomeroy, Pike, Beals, & Manoli, 1999).

Johnson (1983) reports on findings from a small (n=11) surgical study, and supports the view that the average age (49 years) and gender of participants recruited to this study suggests that PTTD is a condition of adult women. However, since the study was only concerned with the diagnosis and management of total tendon rupture, it offers little to our understanding of the epidemiological features of broader PTTD. Since the sample size was small, and little information is available regarding the design of the study, it is difficult to assess whether this research represents a true clinical picture.

In a later study, Holmes and Mann (1992) studied the possible epidemiological factors associated with PT tendon rupture. The investigation involved the retrospective analysis of medical records of 67 patients with flat foot deformity or PT tendon rupture. The analysis revealed that the pathologies were predominantly presented in females of between the age of 51 and 87 years. Correlations were found between hypertension, diabetes and obesity. Although this study has added to the existing knowledge of PTTD, it must be acknowledged that the study design was non-experimental and also, due to the small sample size, there were a large number of confounding variables that could not be accounted for in the data analysis. For example, no information was given about the time since diagnosis of hypertension, diabetes or obesity. Information regarding the severity of these coexisting conditions is absent from the detail outlining the methods used for the study. It may be that the majority of the study cohort had well controlled newly diagnosed hypertension, or conversely were long-standing poorly controlled hypertensive patients. Data detailing co-morbidities, such as obesity coupled with hypertension, is absent. There is no information available regarding the stage of the disease at diagnosis. This has significance, as knowing what the risk factors are would only be advantageous if coupled with early diagnosis and early intervention of the condition. The data suggests that perhaps the majority of patients in the older age group (51 out of 67) had received a progressed late stage diagnosis since the confirmation of PT rupture was made at the time of surgery

It is important to note that the data was extracted from the patient notes at certain time points. For example, the results suggest that the mean time from symptom onset to diagnosis of PTTD was two years. As there is no information regarding a pre-diagnosis

period, this delayed diagnosis could be an important factor leading to the rupture of the PT tendon. It may be that the tendon gradually degenerates over a period of two years as a consequence of abnormal lower limb biomechanics. This is a reasonable hypothesis if it is accepted that this disorder is progressive. In order to support these data and test these hypotheses future studies should aim to be prospective in design and consider using a larger sample size and more robust data collection procedures.

Both Fenn and Chiodo (2006) and Pomeroy et al. (1999) cite Holmes and Mann (1992) in two review papers providing an overview and discussion of current concepts of PTTD, however neither author provides any new information regarding the epidemiological features of this condition.

Other risk factors identified predisposing to PTTD include genetic factors and associated connective tissue disorders, related ABO blood group chemistry and tendon rupture (Beeson, 2014). Collagen typing has also been linked to the incidence of PTTD. Tendons are thought to be predominantly composed of type I collagen, and much smaller amounts of III, IV and V (Satomi et al., 2008), however recent research into the composition of diseased posterior tibial tendons has suggested that this collagen type changes in the presence of dysfunction (Gonçalves-Neto et al., 2002; Kannus & Jozsa, 1991). A 40% reduction in type I and an increase of type V (26%), and type III (53%) has been reported (Gonçalves-Neto et al., 2002).

An often-quoted clinical phrase is that a hypo-vascular area approximately 2-4cm proximal to the insertion point on the navicular and distal to the medial malleolus exists. Clinical reasoning suggests these locations are significant as they are related to the two points that are likely to undergo the highest stress; the retro-malleolar area because of the potential compression of the tendon against the malleolus as the tendon changes direction and the navicular as it is the main insertion point. Although this reasoning is plausible, however, the evidence to support it is varied.

Harris (1942), cited by Frey (Frey, Shereff, & Greenidge, 1990), was the first to suggest that there may be a link with hypo-vascularity and pathology at the posterior tibial tendon. Results from a 28 tendon cadaver study report consistently observing hypo-vascularity at the mid portion of the tendon (Frey et al., 1990). Peterson et al. (Petersen, Hohmann, Stein, & Tillmann, 2002) hypothesise that there may be an a-vascular (as

opposed to a hypo-vascular) region at this point. However, the anatomical location remains controversial and more recent research has challenged this assertion (Prado, 2006), with findings from an 80 tendon cadaver study being in direct contrast to the findings of Peterson and Frey (Frey et al., 1990; Petersen et al., 2002).

There is only one published study that has addressed the prevalence of PTTD in the UK population; that of Kohls-Gatzoulis, Woods, Angel and Singh (2009). Participants were asked to complete a questionnaire that asked them whether they had problems with their feet and if so, if they thought that they had flat feet. Patients were then asked specific questions relating to their foot pain and foot shape; for example, whether their foot shape had changed, and whether they had arch pain, or whether there was swelling present on the inside of the ankle. The questionnaire was distributed to a population of female patients over the age of 40. The participants were selected at random from a GP Practice database of general patients registered at the practice. The database was kept up to date by the practice staff. There were, in total, 1922 patients in the practice who were 40 years of age or over and female. A random number generator then selected 1000 of these patients to complete the questionnaire.

A total of 582 completed questionnaires were returned. Of these responses, 360 (68.1%) women reported having no problems with their feet. Two hundred and twenty-two participants (38.2%) indicated that they did have foot problems, with 106 (17.7%) reporting forefoot problems only. The remaining 116 (19.9%) were contacted by telephone to clarify the nature of their foot problems, and of those, 79 (13.6%) were asked to attend the podiatry clinic for a more detailed assessment. Seventy-five percent attended their appointment and of those a diagnosis of symptomatic flat foot was made in 9 cases, 7 patients were diagnosed with stage one PTTD, 12 patients with stage two PTTD and a further 9 were diagnosed with acquired adult flat foot deformity. Out of the 37 diagnoses made, only 5 had previously been given a diagnosis and were receiving specialist care. The prevalence therefore was 6.6% for flat foot pathology, and for PTTD the prevalence was 3.3%.

Although this study has made a considerable contribution to our understanding of the prevalence of PTTD, it also highlights the fundamental problems associated with the accurate diagnosis of the condition, in particular the classification of stage I. This information adds to the above discussion, in that PTTD is often diagnosed at a later stage

and therefore there is a significant delay in the patient receiving therapeutic interventions. This gap in the knowledge concerning identification of the early stages of PTTD and lack of understanding of the progression of the disease emphasises the need for clinicians to come to a universal understanding to standardise assessment and classification of the stages of development of PTTD. Without this key information, including the validation of assessment tools, the collection of epidemiological and prevalence data will inevitably be inaccurate. The stages are listed and discussed in detail in a later section of this chapter.

2.4 Aetiology

There is a lack of agreement surrounding the aetiology of PTTD. Researchers working in the field of musculoskeletal medicine differ in their opinions regarding the causes of PTTD, describing the condition as having an unknown aetiology or a poorly understood complex aetiology (Barn, Turner, Rafferty, Sturrock, & Woodburn, 2013; Bowring & Chockalingam, 2010; Lake, Trexler, & Barringer, 1999; Smita Rao, Riskowski, & Hannan, 2012; Semple et al., 2009; Singh, King, & Perera, 2012; Yao, 2015). As the pathophysiology of the development and progression of PTTD involves the disruption and disorganisation of specific tissues within the tendon, the aetiology of the condition is multifarious in nature. This is exemplified by the associated changes in other soft tissue structures, such as plantar ligaments. Although research by Balen & Helms, (2001); Deland, de Asla, Sung, Ernberg, & Potter, (2005) has not identified the precise role of ligaments in the diagnosis, aetiology and contribution to PTTD, the results suggested that the majority of individuals with PTTD also present with a damaged superior medial component of the spring ligament and significant abnormalities within the sinus tarsi, particularly to the talocalcaneal interosseous ligament (Balen & Helms, 2001).

A further study by Deland et al. (2005) reported the presence of abnormalities in numerous ligaments of the foot in patients diagnosed with PTTD. Using magnetic resonance imaging (comparing age-matched controls), Deland (2012); Deland et al. (2005) were able to identify the superior medial component of the spring ligament as “at risk” of injury compared to other ligaments likely to affect the profile of the medial longitudinal arch.

Information regarding the stage of PTTD at the time of diagnosis of the participants in the cited studies is unclear. Without this information it is impossible to establish at which point the posterior tibial tendon becomes truly dysfunctional in terms of the development of pes planus and therefore at what point the plantar ligament becomes involved in the dysfunction. It could be that abnormalities observed in the spring ligament can occur before the involvement of the PTT in pathological flat foot.

2.5 PTTD and spring ligament involvement

The contribution of spring ligament dysfunction to the development of a flat foot deformity has been debated within the literature (Jennings & Christensen, 2008; Mengiardi et al., 2005; Taniguchi et al., 2003). It would appear that this ligament may be a key structure in maintaining the integrity and the architecture of the foot. The function of the spring ligament is thought to be associated with both the subtalar joint and the medial longitudinal arch (Mengiardi et al., 2005). The calcaneonavicular ligament, as it is also known, is reported to have a primary function in providing stability to the medial longitudinal arch of the foot. Additionally it is thought to provide support to the talar head by contributing to the formation of the articular cavity or acetabulum pedis (Mengiardi et al., 2005). It has been suggested that the spring ligament has some involvement in the development of PTTD. However, there remains some debate over the anatomical make-up of the spring ligament itself (Jennings & Christensen, 2008). Some authors refer to the superomedial and inferior aspects of the ligament (Jennings & Christensen, 2008), while others refer to a third component (Mengiardi et al., 2005; Taniguchi et al., 2003), which is often overlooked but could be significant when defining the role of this ligament (Figure 14) (Taniguchi et al., 2003). Research which involved sectioning the spring ligament in cadaveric specimens (Jennings & Christensen, 2008), as well as in vivo MRI assessment of the spring ligament in patients with a diagnosis of PTTD (Balén & Helms, 2001), suggests that this ligament may play a more vital role than originally thought.

Work conducted by Mengiardi et al. (2005) and Taniguchi et al. (2003) has identified the presence of a 'third ligament' within the spring ligament complex. The authors consistently found this third portion of the ligament, that was apparent both in the cadaver dissections (n = 5) and the MRI for both the asymptomatic subjects (n = 78) and the cadaver images.

The tri-partite ligament runs from between the middle and anterior calcaneal facets to the navicular tuberosity. The superomedial component runs along the anterior border of the middle facet of the calcaneus. The superficial fibres of the ligament merge with the tendon sheath of the PTT and the deeper fibres insert onto the medial articular facet of the navicular. The inferior component runs along the notch between the anterior and middle facets of the calcaneum and inserts onto the navicular beak (Figure 14) (Mengiardi et al., 2005).

Meagan and Jeffery (2008) attempted to establish the contribution that the spring ligament makes to the development of flat foot deformity. The five specimen cadaver study attempted to mimic the stance phase of gait. Having dissected out the main muscle compartments of the leg exposing the main tendons (triceps surae, peroneus longus and brevis, flexor digitorum longus, flexor hallucis longus and PTT), each structure was subjected to a loading pattern replicating load during the stance phase of gait. Each musculo-tendinous structure was tested before and after sectioning of the spring ligament, and before and after sectioning of the PTT. Each structure was loaded at 0%, 50%, 100% and 150% of its calculated force strength during the stance phase. Three-dimensional kinematic analysis was used to measure the positions and rotations of the talus, navicular and calcaneus. The results suggest that sectioning of the spring ligament complex significantly alters the architecture of the foot and that with re-loading of the posterior tibial tendon these changes are not significantly reduced. This suggests that the primary aetiological factor involved in the development of flat foot deformity may rest with an inefficient spring ligament complex. However, there are a number of issues with this type of study. The study gives no added information as to whether PTT insufficiency occurs as a primary or secondary problem. Also unknown is the foot posture of the cadaver specimens. This may be a limitation as previous studies have suggested that foot posture, in particular pronated foot posture, could place an individual at increased risk of developing PTTD (Yeap, Singh, & Birch, 2001). The specimens were loaded 100 times to mimic ambulation, suggesting that this simulation represents 100 steps.

Considering that the average individual may walk in excess of 1000 steps and up to 10,000 steps a day, this is suggestive of significantly reduced mobility and arguably does not come close to a 'real situation'. This may be important particularly since PTTD is referred to as a progressive disorder, and is assessed clinically in this way (Bluman, Title,

& Myerson, 2007; Johnson & Strom, 1989; Myerson, 1996). The fact that a mid-stance simulation was carried out and that the PTT is actually most active during the beginning and end of the stance phase and not at the mid-stance point is a significant limitation. What this study does suggest is that the spring ligament appears to have a significant function in maintaining the stability of, and the arch profile of, the foot, but it says little about its interaction with the PTT. This remains one of the unanswered questions facing clinicians.

2.6 Assessment and the progression of PTTD

The development of assessment criteria for PTTD has largely been led by the orthopaedic community. The existing criteria suggest that it is possible to identify discrete stages in the clinical signs and symptoms of the progression of the pathology (Bluman et al., 2007; Johnson & Strom, 1989; Kohls-Gatzoulis, Angel, et al., 2004a). The adoption of this approach will allow for the identification of a relationship between the presenting symptoms and clinical features of specific stages of PTTD. Such a framework for the classification of different stages of PTTD is said to be essential for successful clinical diagnosis, however the scientific rigour surrounding the sensitivity and specificity of the clinical features at each stage is limited, and there is a paucity of published work in this area.

Currently, the classification models used in clinical practice include surgical interventions for stages of PTTD, in addition to suggestions for conservative management in the early stages. Classification systems such as these are subject to interpretation, and therefore may suffer inter-rater and intra-rater variability. As the current classification systems are aimed predominantly at providing a framework which may ultimately aid timely surgical intervention, there is little recognition or acknowledgement within the literature of the merits of early conservative management, that could be provided by the podiatric profession. As discussed previously in this chapter, research has shown that PTTD is often poorly diagnosed (Kohls-Gatzoulis, Angel, et al., 2004a; Rattanaprasert, Smith, Sullivan, & Gilleard, 1999) and it is perhaps the lack of quantitative measures to establish the progression of the deformity that inhibits awareness of this condition.

In 1989 Johnson and Strom (1989) reported on the various stages of the pathology as it progressed. This three stage classification system along with the suggested treatment and

management remained the main classification criteria for approximately ten years. At this point a fourth stage was added to the classification in recognition that the Johnson and Strom system did not accommodate all the variations seen clinically (Johnson & Strom, 1989; Kohls-Gatzoulis, Angel, et al., 2004a).

Myerson (1996) added a fourth stage to the classification, identifying that at end stage the rearfoot is in a valgus state and is rigid, with the only available treatment option being a fixed AFO and a triple arthrodesis of the rearfoot and ankle.

In 2007, Bluman et al. (2007), published a redefined classification system which has several subdivisions for each stage (I-IV), taking into account other previously unclassified signs, such as forefoot supination, forefoot abduction and medial column instability. Stage I is identified as paratendinitis or partial rupture and is further subdivided into inflammatory disease, partial tear with 'normal' hindfoot anatomy and partial tear with mild hindfoot valgus.

Stage II features are identified as significant attenuation of the tendon or frank rupture. Stage II is subdivided into three sub categories and the first sub category is further divided twice more. Stage II a, recognises hind foot valgus as the main defining feature, some forefoot supination may also be apparent. Stage II a1 is characterised by the definitive presence of forefoot varus on correction of the valgus forefoot. The forefoot varus is flexible and can be passively corrected. Stage II a2 is characterised by a rigid, fixed forefoot varus. The rearfoot remains flexible.

Stage IIb is characterised by forefoot abduction usually in conjunction with rearfoot valgus. The midtarsal joint complex may be the primary joint involvement or the metatarsal cuneiform joints, commonly presenting as OA at the second metatarsal cuneiform joint. These features are best viewed on x-ray in order to distinguish them (Bluman et al., 2007).

Stage IIc is characterised by medial first ray instability, this being the most salient presentation of this stage. The authors state that the unstable first ray causes the rearfoot to pronate. The forefoot remains in supination (forefoot varus) and is fixed. The foot, according to Bluman et al. (2007), when placed in neutral at the rearfoot, causes the first ray to dorsiflex, thereby causing the subtalar joint to pronate causing impingement. However, the alternative way of viewing this, and the more conventional way, would be

to suggest that as the pathology is progressing the rearfoot progresses into a valgus position. This in turn causes the first ray, which is a mobile unit, to progress into a dorsiflexed position. During the propulsive phase of gait the windlass mechanism is inhibited and the gait becomes a-propulsive or at least lateral loading. The other reason for the rearfoot to pronate would be to compensate for the forefoot varus, or as described by Bluman et al. (2007), forefoot supination. This would not allow sufficient forefoot contact to occur at mid-stance or forefoot loading and would render the foot unstable as a result of the subtalar joint compensatory pronation. This again would have the net effect of pushing the first ray into dorsiflexion, inhibiting the windlass mechanism and rendering the entire foot unstable and a-propulsive. This would have a negative impact on both the posterior tibial tendon, and the remaining ligaments attempting to resist abnormal rearfoot pronation.

The final stages are not dissimilar to each other and to previously published guidelines, both referring to a rigid rearfoot deformity. Stage III is associated with advanced tendon rupture and is characterised by rearfoot valgus which is rigid and there may also be a forefoot deformity, and often rigid forefoot abduction.

Stage IV is associated with advanced stage rupture, resulting in both of the above, but also includes a group with iatrogenic tibiotalar valgus, where misalignment may have occurred. There is also likely to be deltoid ligament insufficiency.

Using this classification system, all apart from stage I require surgical intervention ranging from tendon transfers to triple arthrodesis. Whilst the stage I criteria acknowledge that there may not be any rupture present, the sub-categories only accommodate non-rupture when referring to inflammatory disease, where the paratenon may be inflamed secondary to systemic disease such as rheumatoid arthritis.

One of the problems with the current available classification systems is the focus of the model. The three main classification systems in clinical use have been presented as work that builds on the previously proposed classification. For example, Myerson (1996) builds on the work of Johnson and Strom (1996). Bluman et al. (2007) builds on the work of Myerson (Myerson, 1996), and Johnson and Strom (1989). However, the title of the classification changes each time and hence the focus of the refined classification will also change. The original classification proposed by Johnson and Strom (1989) refers to

posterior tibial tendon dysfunction. This would suggest a broad range of presentations of the condition from early onset right through to total rupture. However, the latest modified version (Bluman et al., 2007) refers to posterior tibial tendon rupture. This would suggest a much narrower focus. Raikin, Winters, and Daniel (2012) describe the characteristics of a systematic approach to adult acquired flat foot. A recent publication by (Abousayed, Tartaglione, Rosenbaum, & Dipreta, 2015) has criticised the dearth of evidence validating the above classification/assessment tools. It also provides advice concerning the confusing and multiple terminologies used to describe PTTD. Potential confusion may predispose the use of the range of classification tools since each successive author claims to have refined or expanded on the earlier work. Whilst this may be so, however, it is also important to consider the focus of the work presented.

There is no consensus regarding the terminology used to describe the condition, and more notably, little recognition of the evidence which suggests that, if diagnosis is made early, then conservative intervention that could be provided by a podiatrist may negate or at least defer the need for a surgical referral and subsequent surgical intervention. If a combination of approaches could be adopted utilising conservative podiatric intervention with surgical intervention when indicated, it may reduce the need for more radical surgery which carries significant undesirable effects for foot function.

Although it is generally accepted both clinically, and from the available published evidence, that PTTD is progressive and does lead to an acquired flat foot deformity, one publication appears to contradict this accepted understanding.

Yeap et al. (2001), investigated the effect of tendon transfer of the posterior tibial tendon and the effect on foot shape and development of pathological flat foot deformity. The study findings suggest that acquired adult flat foot deformity may not be the result of a dysfunctional tibialis posterior tendon. The research claims that in the small sample group studied none of the patient's demonstrated signs of posterior tibial tendon dysfunction, or consequent flat foot deformity. However, there were aspects of the work that makes it difficult to evaluate. The sample size was small (n=17). Of the 17 included in the study, the time scale from surgery to retrospective follow up ranged from 7.5 months to 25 years. The patients seen were being investigated and treated for foot drop not PTTD, this is something that appears to be a fundamental flaw in the structure of the project. The

results of this study have not undergone statistical analysis and their significance therefore remains unclear.

2.7 Measuring dynamic foot motion

Historically, foot motion has been assessed with motion data systems referring to the foot as a rigid, one or two structure unit. This has led to an over simplification of foot function regarding kinematic analysis and also led to the situation where there was virtually no information available to characterise foot function during ambulation in a meaningful way.

One of the reasons for the paucity of information about kinematic analysis of the smaller joints of the feet may be the difficulty of obtaining information using marker based motion based analysis due to the size of the markers required, and the need for them to be in close proximity when capturing the information.

However, because of the growing use of optical based motion analysis for clinical outcomes and the consequent increase in the development of foot based models, there are now several foot based marker sets available and so the area of foot kinematics is beginning to expand.

2.7.1 Kinematic considerations

Over the years a number of kinematic foot models have been proposed. The Milwaukee foot model, developed and validated in 1996 (Kidder, Abuzzahab, Harris, & Johnson, 1996), utilised a four segment rigid body model of the foot and ankle, consisting of the tibia and fibula, the calcaneus, talus and navicular, cuneiforms, cuboid and metatarsals, and the hallux. The authors based their findings on a single test patient. The model has since been validated for use with children (Myers, Mei, Marks, & Harris, 2004). Although this model is often utilised it does have some shortcomings over other models such as the Oxford model. The model proposed for the Milwaukee marker set is similar to the Oxford foot model (Carson, Harrington, Thompson, O'Connor, & Theologis, 2001), with a number of additions. The posterior aspect of the calcaneus has been modified to include a wand marker and the sagittal plane axis for the forefoot is determined by an additional marker placement at the dorsal 2nd/3rd metatarsal head. An alteration to the Milwaukee model removed the first metatarsal head marker due to excessive skin marker movement.

Leardini, Benedetti, Catani, Simoncini, and Giannini (1999a) proposed a multi-segment foot model, named after the institution where it was developed, Istituto Ortopedico Rizzoli (IOR). An array of markers mounted on rigid plates adhered to the skin with metal clamps and double sided tape were utilised. The authors report consistency for all parameters measured and repeatability studies have shown significantly reliable results. Similarities were comparable with some reported data, however, the work by Kidder et al. (1996) did not correspond well. Since its initial validation the IOR foot model has been updated to improve output (Leardini et al., 2007).

This issue of comparability is one of the shortcomings of using different models for collecting foot and ankle kinematic data. This has been highlighted by Stebbins, Harrington, Thompson, Zavatsky, and Theologis (2006), and was one of the main drivers for developing a standardised model for foot and ankle kinematic analysis.

The Oxford foot model findings were reported initially in 2001 (Carson et al., 2001) and since then further work and the publication of a repeatability study in healthy non-pathological children has been reported, using the same multi-segment foot model (Stebbins et al., 2006). The original investigation (Carson et al., 2001) concentrated on the development of a multi-segment foot model and measurement protocol for clinical and research use and later studies looked at its reliability.

The study by Carson et al. (2001) used a three segment foot model; hindfoot, forefoot and hallux with additional tibial segment. The rearfoot was represented by the calcaneus and talus, the forefoot by the five metatarsals, and the hallux by the hallux and proximal phalanx. The results were similar to those already established for foot kinematics and demonstrated an acceptable level of repeatability for each of the intersegment angles. The authors suggested that the study provides a foundation for objective foot measurement in gait analysis for research and clinical application.

Since this first report there have been further publications (Kothari, Dixon, Stebbins, Zavatsky, & Theologis, 2014; Stebbins et al., 2006) utilising the Oxford multi-segment foot model. Stebbins et al. (2006) reported on repeatability, using this foot model for analysis of kinematics in children, and later Kothari et al. (2014), used it to track the navicular, comparing different foot postures in children. The authors made several changes to the original marker sets used, including a re-definition of the tibial segment using the knee

joint centre. The hindfoot segment was altered to enable independence from other segments. For the forefoot segment, the positioning of the hallux marker lateral to the extensor tendon enabled greater consistency in marker placement.

The results of this study have enabled the Oxford team to develop and validate a multi-segment foot model which is suitable for use with children and is also suitable for use when pathology is present. Stebbins et al. (2006) confirmed that only negligible differences were found when measuring angles in slightly different ways, offering some flexibility in implementation in the presence of severe deformity.

In a further study by Curtis, Bencke, Stebbins, and Stansfield (2009), the Oxford model was used to test repeatability for specific segments of the foot, according to the three rockers described by Perry (1992.), collecting data on two separate occasions and three trials of data per subject. The data was also compared with data collected from Oxford to establish inter-centre repeatability. The results suggest that discrepancies exist for frontal and transverse plane motion for the rearfoot rocker. This is perhaps to do with the way in which a neutral position is established. Repeatability was maintained for the rear foot for the three trials suggesting that there is good repeatability for the Oxford model throughout the gait cycle. However, the results of this study suggest that there may be discrepancies for inter-centre comparisons for repeatability for the rear foot in the frontal and transverse planes. The authors suggest that further studies are required to determine the inter-centre repeatability especially for the rear foot.

An alternative model by (Simon et al., 2006), known as the Heidelberg foot measurement method, published initial validation findings in 2006. The technique described by the authors uses a seventeen marker placement for analysis of the leg, foot and ankle. In order to provide some standardisation and repeatability of marker placements where there were no defined bony landmarks or reference landmarks (for example, for the rearfoot medial and lateral markers) a heel alignment device (HAD) was developed and tested. The method was tested for reliability, for test and re-test, inter-rater reliability, internal consistency and accuracy.

The model proposed was primarily aimed at providing a multi-segment model that could be consistently applied to pathological feet. As part of the testing procedure, the authors report that data was collected for 50 pathological foot deformities. Within the reported

results the data for this group is not presented. The authors state that the results from the 50 pathological feet were “very satisfactory”. However, without sight of the data, users of this evidence can only make assumptions regarding pathological feet.

The authors (Simon et al., 2006) report on the ankle joint complex, including the subtalar joint and ankle joint, as a two hinge joint. Due to the complexity of the motion produced at the subtalar joint and the fact that motion occurs in three planes as opposed to one plane that would have been assessed with a hinge joint model, this method of assessing the subtalar joint complex is a significant limitation. The authors support this arrangement claiming that by representing the rearfoot in this way it is possible to reduce the motion to the main anatomical rotation. The study utilises a heel alignment device; the authors state that the representation of the talus by utilising markers on the calcaneus is a valid approach for the normal ankle joint as calcaneal motion can be attributed primarily to rotation at the subtalar joint. This may be the case; however, this would only take into account frontal plane motion and as alluded to above, subtalar joint motion is referred to as tri-planar. This would significantly limit the accurate depiction of motion at this joint.

The relationship between skin markers and the reality of the anatomical landmarks and subsequent segmental relationships is an important point, however, to simplify the actual motion that does occur by manipulating marker placements may not be the best way forward.

Limited work has been conducted into the relationship between surface placed markers and bone pin markers in order to further clarify this point. Nester et al. (2007) investigated kinematic data taken from a four segment foot model and compared it to the kinematic motion of the individual bones comprising each segment. The argument presented is twofold. First, it is an over-simplification to propose that the foot can be modelled as a series of rigid segments, and second, skin movement artefact is often cited as one of the key problems involved with collecting such data. Although authors using the rigid segment models have reported on reliability findings there has been very little work examining the precise relationship that this external data collection method has with the kinematics of the underlying bony configuration comprising each segment.

Additionally, the study sought to establish differences between different protocols. The two protocols studied were skin marker placements such as those used in the Carson et al. (2001) study, and markers attached to plates mounted on the skin surface, as proposed by Leardini et al. (1999).

The results of this novel study (Nester et al., 2007) were inconclusive. Significant differences were found between protocols (data collected for the skin mounted markers, plate mounted markers and bone pin marker placement). However, due to the fact that the data was collected on three separate occasions, some differences are to be expected. This is, in part, due to the differences in the quiet standing positions adopted as the baselines in order to compare dynamic marker placement trajectories. The authors Nester et al. (2007), conclude that it is not possible to say clearly whether skin or plate mounted protocols are preferable. It also appears to be unclear where differences may lie with regard to these protocols and the bone marker placement, as motion data between subjects, joint motions or planes of motion were inconsistent. However, what seems to be suggested in the conclusion to the paper is that, rather than thinking about absolute values based on bone marker movement, perhaps concentration should be focussed on how the foot can be modelled as a rigid body segment rather than which marker set should be used.

A recent review has suggested that, in order to appreciate fully the clinical utility of the available foot models, there must be a continuation of the validation work, extending to patient populations and pathological foot types. Deschamps et al. (2011) recommend that future work should focus on robust repeatability studies. Priority should be given to between day, between trial and between clinician and subject repeatability, in order to improve the use of foot models in clinical practice and on pathological feet.

2.8 Kinematic and kinetic assessment in patients with PTTD

Kinematic and kinetic analysis can provide a comprehensive picture of the changes that may take place in foot and ankle movement during gait in the presence of pathology. Sophisticated equipment can detect small changes in movement and force. Data processing software can build an accurate and reliable 'model' of the way in which a patient mobilises during gait and give information regarding the forces involved to bring about such movement.

Changes in the kinematic and kinetic variables in patients with PTTD are an under-explored area, with relatively few studies reporting findings specifically related to foot function.

In 1999, Rattanaprasert et al. (1999) reported the three dimensional kinematics of one case without a functioning PTT, and compared their findings to a mean of data collected from 10 normal subjects. The results report differences in rearfoot and forefoot motions, with most of the differences occurring through late stance and propulsion. Sagittal plane motion with the leg relative to the rear foot and with the forefoot relative to the rearfoot, and adduction/abduction ranges of motion were particularly different. Temporal characteristics also changed when comparing the PTTD case with the amalgamated mean figures for the 10 normal subjects. This study gives an insight into possible changes that might occur in PTTD, however the case used was atypical of a classic presentation of PTTD, and it is therefore not possible to say if this data has provided an accurate picture of the changes seen in PTTD.

Neville, Flemister, and Houck (2013); J. Tome, D. A. Nawoczinski, A. Flemister, and J. Houck (2006), performed three dimensional kinematic analysis of subjects with Stage II dysfunction compared to healthy controls for hind foot eversion and inversion, medial longitudinal arch angle and forefoot abduction and adduction. Results suggest that participants with PTTD demonstrate significantly more rearfoot eversion, a greater medial longitudinal arch angle and increased amounts in abduction of the forefoot. These findings are consistent with others (Ness, Long, Marks, & Harris, 2008; Ringleb et al., 2007). The authors conclude that for this group of patients there is a failure of secondary ligamentous support to control foot kinematics and subjects with stage two dysfunction.

A comprehensive analysis of foot kinematics and kinetics for this group with PTTD has been presented by Ringleb et al. (2007), albeit using a small sample size. This study reports on the electromyography (EMG) activity, foot pressure data, motion data and force plate data in a small group of patients reported to have Stage II dysfunction (Ringleb et al., 2007). It reports significant differences in midfoot and hind foot kinematics when compared to healthy individuals. Interestingly, insignificant increases in rearfoot eversion were reported, seemingly in direct contrast to what would be expected from patients with this condition.

EMG data suggested that in addition to an increase of activity in the second half of the stance phase for tibialis posterior, the same is also true for tibialis anterior, gastroc-soleus complex, with increased, prolonged activity in peroneus longus. There was a reported phasic reversal for peroneus brevis when compared to healthy individuals. Foot pressure data showed significant medial shift in peak pressures.

The surprising results reported for insignificant eversion of the foot PTTD when compared with normal subjects may have been to do with the way in which the baseline data had been collected. The authors' state that the position used for the baseline was relaxed standing. Therefore, if the foot was already maximally pronated there would be no further scope for additional pronation to occur, and therefore this may have appeared to indicate that there was an insignificant increase in eversion compared to normal subjects. The subjects used for comparison were taken from a database of previously collected data and therefore were not matched controls. These subjects had not been collected specifically for this trial. Therefore, it is conceivable that the data collection procedure may have varied, yielding differences in the reported findings.

Ness et al. (2008), investigating kinematic changes in patients with PTTD, report similar findings to Ringleb et al. (2007). The findings from 25 subjects used previously collected data for the comparison. The four segment Milwaukee foot model was employed, collecting data from the tibia, hindfoot, forefoot and hallux, with motion measured to the proximal segment. In addition, temporal and spatial parameters of gait were studied. The findings appear comparable to those that were reported by Ringleb et al. (2007) with one notable difference. The data presented for rearfoot eversion shows a significant increase, as opposed to the insignificant increase reported by Ringleb et al. (2007). Reduction in dorsiflexion was also seen in the sagittal plane for the rearfoot.

Overall ROM deficits were seen throughout most of the stance phase of gait. Interestingly, there were also significant reductions seen in the hallux sagittal plane ROM. However, with an increase in rearfoot eversion, this would have an expected detrimental effect on the function of the first ray, preventing a successful windlass manoeuvre and perhaps causing a functional hallux limitus. Information for non-weight bearing values is not reported. Further clarity regarding the significance of the differences in motion found at the rear foot would be useful as would an indication of the level of significance. Stance

phase duration, stride length, cadence, and walking speed were all seen to decrease in the PTTD group when compared to the normal a-symptomatic group.

2.9 Tests used in the assessment of PTTD

Currently there is little published data enhancing the understanding of why this condition is poorly diagnosed. Similarly, few studies have explored the suspected differences in the interdisciplinary and multi-disciplinary approaches to assessment and diagnosis. More importantly, the data available surrounding agreement on approaches to assessment and diagnosis is scarce (Kroll & Neri, 2009). Some of the 'accepted clinical practice' includes tests that have not undergone quantitative data evaluation. Two of these tests are discussed below.

2.9.1 Single heel rise manoeuvre

A common inclusion of the classifications currently used in practice, detailing the presence of certain anomalies that characterise the condition, is the single heel rise test. The justification for using this test, however, is difficult to find. Moreover, there is inconsistent use of the single heel rise test.

Despite its common application in the assessment and diagnosis of PTTD, there is little documented evidence of consensus about the purpose of the heel rise test, the optimal test parameters, outcome measurements, or the appropriate associated normative values.

2.9.2 History of the heel rise test

The heel rise test is used to assess static weight bearing muscle function. The test is recommended for individuals with PTTD (Bluman et al., 2007; Houck, Neville, Tome, & Flemister, 2009b; Johnson & Strom, 1989; Myerson & Corrigan, 1996; Otis & Gage, 2001). Weakness of the posterior tibialis muscle is thought to contribute to the inability to perform a heel rise task. Clinically, an abnormal heel rise test is observed when the individual cannot perform a heel rise or performs the heel rise with hind foot eversion (fails to invert on rising) (Kohls-Gatzoulis, Angel, et al., 2004a) suggesting that the posterior tibialis muscle is no longer acting to invert the hind foot or that the patient is demonstrating progressive PTTD (Houck, Neville, Tome, & Flemister, 2009a; Houck et al., 2009b).

Despite its adoption for assessing PTTD presence, the origins of the test are varied. Historically the heel rise test, also known as the calf rise test, was utilised to assess posterior muscle strength. Its early use was between 1940 and 1955 when polio was at its most prolific. The 'floor and ceiling' effects of manual muscle testing (MMT) were recognised as problematic in grading maximal and minimal muscle strength, particularly in this group of patients. The floor effect is noted when individuals repeatedly score the lowest possible score and the ceiling effect when individuals repeatedly obtain the highest possible score. However, this measurement is subjective because it depends upon the strength of the examiner who applies the manual resistance force. (Harris-Love et al., 2014; Lunsford & Perry, 1995).

2.9.3 Kinematic changes during the heel rise test

In light of this, and recognising the inadequacy of the non-weight bearing test, the standing heel rise test was introduced as a substitute, providing a weight bearing method of assessing posterior muscle strength. In two recent studies investigating the kinematic changes associated with this test (Hébert-Losier & Holmberg, 2013; Houck et al., 2009b), researchers in one study (Houck et al., 2009b) revealed that the kinematic changes during a bilateral heel rise test showed a similar pattern to the non-PTTD control group. During the dynamic heel rise test the kinematics of rear foot eversion in the PTTD group were not found to be significantly different from controls.

However, the same study (Houck et al., 2009b), demonstrated significantly different segmental relationship. That is to say, that while the observable kinematic changes showed similar characteristics in terms of pattern, this was relative to the PTTD baseline taken from a pronated foot type. Other interesting findings to note include first metatarsal function which demonstrated a more dorsiflexed position than the control group, and first metatarsophalangeal joint dorsiflexion which demonstrated reduced dorsiflexion in the PTTD group.

Notwithstanding the significance of these results, participants in this study (Houck et al., 2009b) were required to perform a bilateral heel rise. The most common method for conducting this test is for patients with PTTD to perform a single heel rise. A single heel rise is preferable over bilateral heel rise because the contralateral limb could compensate for a loss of function on the ipsilateral limb being tested.

In a more recent study (Chimenti, Tome, Hillin, Flemister, & Houck, 2014), investigating age related differences in performing a single heel rise test for Stage 2 PTTD compared to controls, other factors were highlighted that differ between control and pathology groups. These differences, include, maximum heel height, differences in kinematic rearfoot, forefoot joint motion, increased first ray dorsiflexion and reduced maximal ankle plantarflexion in the PTTD group. Until now these metrics have not been considered when assessing the results of the single heel rise test in PTTD.

2.9.4 Validity and reliability of the single heel rise test

A systematic review (Hébert-Losier, Newsham-West, Schneiders, & Sullivan, 2009) investigating the calf rise test, found poor concordance to specific test criteria. No definitive normative values were determined. Utility of the test in patients with pathology remained unclear. Although adapted for use in several disciplines and traditionally recommended as a clinical assessment and rehabilitation tool, there is no uniform description of the calf-rise/heel rise test.

Work conducted by Hébert-Losier and Holmberg (2013) suggests that the functioning of the gastroc/soleus musculature changes depending on knee position. The purpose of this study was to establish the relative contributions of the gastroc/soleus musculature. Previous research had investigated this, however the kinematic and kinetic changes when conducting the test on an incline had not been previously explored.

In a repeated measures design, participants were required to perform a single heel rise test on an incline under two test conditions; a zero degree and a forty-five degree angle of knee flexion. In the older population, 40-60 years (as would be the case for PTTD), the findings of this research (Hébert-Losier & Holmberg, 2013) indicate that the height of the single heel rise decreases with increases in knee flexion angle, which may occur due to the effort required to maintain a stable base of support, flexing the knee to lower the centre of mass to improve balance. This finding was also linked to the COP result which showed a minimal medial/lateral shift at maximum heel height. Both these findings were accentuated following prolonged testing.

Several recommendations for standardising the single heel rise test have been suggested (Hébert-Losier et al., 2009). By adopting these parameters for research the face validity of the test will improve. They include:

- Ankle starting position; i.e. position of the foot in relation to the tibia
- Knee starting position (flexion/extension)
- Height of the rise
- Pace (rises/min)
- Balance support; e.g. fingertip support
- Outcome measurements; e.g. number of rises, force measurement, degrees of plantarflexion, etc.
- Termination criteria; e.g. pain, unable to maintain, fatigue, etc.

Repetitive single heel rises have appeared in a number of publications, ranging from 3 to 15 repeated single heel rise tests (Harris-Love et al., 2014; Jan et al., 2005; Sferra & Rosenberg, 1997; Supple, Hanft, Murphy, Janecki, & Kogler, 1992). This attempt to quantify the number of heel rises needed to determine normal posterior muscle function and thereby set the benchmark for normalcy, has added to the complexity of interpreting the findings.

Test retest reliability (Lunsford & Perry, 1995) of the single heel rise test, according to ICC and SEM results, suggests that the test is reliable for testing posterior calf musculature although interestingly, the use of this test in relation to PTTD was absent in this study (Lunsford & Perry, 1995). Results confirmed that repeated single heel rises provided similar parameters in terms of number of rises performed, heel height measured, and maximum ankle plantarflexion, when carried out on different days. Limitations relate to the non-pathological participant group used in this study. Results for reliability/repeatability may be very different for a pathological condition such as PTTD in which symptoms tend to be progressive and variable.

A study utilising the single heel rise test in women with myositis (Harris-Love et al., 2014), comparing two methods of manual muscle testing (MMT) with the single limb heel rise test, support the notion of the problems associated with the ceiling and floor effects previously mentioned (Harris-Love et al., 2014; Lunsford & Perry, 1995) elsewhere in this review. Furthermore, Harris-Love et al. (2014) propose that the maximum number of heel

risers is a poor indicator of muscle strength. The authors also found that MMT was not predictive of muscle weakness or dysfunction.

2.9.5 Biomechanics of the single heel rise test

Some publications have linked the function of the posterior muscle group to the biomechanics of the foot; considering function in relation to the proximity of the posterior muscle group insertions to the sub-talar joint axis. The premise is that, in a pronated foot type, this axis position may shift more medially.

Previous work (Barn et al., 2013; Ringleb et al., 2007) tested muscle activity using fine wire EMG. In both studies the activity of the PT muscle increased. The same authors also reported increases in the inversion moment during stance in participants with Stage II PTTD compared to controls. Chimenti et al. (2014), identified that kinematic changes were present in patients with Stage II PTTD. This suggests that there are alternative reasons other than muscle strength and activity to explain these differences. This point is not surprising since in PTTD the pathology lies with the tendon and not the muscle belly itself, therefore there is no reason for muscle activity to be compromised. The kinematic changes identified in Stage II PTTD (Chimenti et al., 2014) include a reduced heel height compared to controls, reduced maximal ankle joint plantarflexion and increased first ray dorsiflexion. The increased first ray dorsiflexion is indicative of a pronated foot type, whereby the windlass function is impaired due to the foot failing to re-supinate at the mid/terminal phase of stance (Durrant & Chockalingam, 2009).

Perhaps a secondary effect due to the progressive nature of PTTD, and the gradual development of pes planus, is to effectively move the effort (the insertion of the PT tendon) closer to the subtalar joint axis, thereby reducing the mechanical advantage. This could be one explanation why there is an increase in muscle activity in order to restore the net moment generated by the PT muscle contraction and subsequent application of the force via the tendon insertion.

The majority of the published work investigating the single heel rise test stems from its use to test plantarflexion muscle strength in poliomyelitis sufferers. Until recently there has been very little work isolating the tibialis posterior muscle activity in dysfunction. The interpretation of this test and its significance in the assessment of PTTD are worthy of debate.

The tibialis posterior muscle lies within the deep posterior muscle group and has a function in both sagittal plane ankle joint plantarflexion and frontal plane foot inversion. The single heel rise test used in the assessment of PTTD signifies pathology if there is an absence of heel inversion on rising. The absence of heel inversion could be affected by the forces acting across the subtalar joint axis, affecting lever arm function. These forces would be generated by internal muscle contraction. If there is an internal force deficit in the presence of PTTD, due to pain performing the single heel rise test, then this would adversely affect the outcome of the test, but not necessarily because of muscle weakness, more because of a protective mechanism. Similarly, if patients with PTTD have normal unaffected muscle contraction, how would this affect the clinical observations alluded to throughout this paper? The test is not used to test ankle joint plantarflexion strength in the presence of PTTD, however the majority of the literature relates to the use of the test in this way. Therefore, the points made previously by other authors may not be valid for this particular patient group. The relative contribution the isolated PT muscle function makes to ankle joint plantarflexion and rear foot inversion is not known, and the interpretation of assessment findings is thus inconclusive.

2.10 Navicular displacement (navicular drop and navicular drift)

Navicular drop and navicular drift have a long association with foot posture. Navicular drop was the first measure to be used to predict foot posture.

Both navicular drop (NDro) and navicular drift (NDri) have been used as indicators to describe the characteristics of arch profile and foot posture and also to infer how these characteristics may be altered in foot pathology (Barton, Bonanno, Levinger, & Menz, 2010; Baxter, Baycroft, & Baxter, 2011; Brody, 1982; Mills, Blanch, Dev, Martin, & Vicenzino, 2012; Rathleff, Nielsen, & Kersting, 2012; Tong & Kong, 2013; Vicenzino, Griffiths, Griffiths, & Hadley, 2000).

2.10.1 History of the navicular drop and drift test

Previous research has confirmed that NDro and NDri contribute to our understanding of foot shape and function. Traditionally NDro (Brody, 1982), and later NDri (Menz, 1998), have been obtained using static weight bearing assessment techniques. Historically, for NDro measurements, the method proposed by Brody (1982) requires the difference in position of the navicular, signified by a line marked on the foot with a pen when the foot

has been placed in a neutral or congruent position, and a second line drawn onto the foot after the participant has been instructed to relax the foot, to be calculated. The NDri test (Menz, 1998) records the mediolateral displacement (transverse plane movement). Measurement of this movement is obtained by projecting onto a card situated under the patient's foot the position of the navicular when the foot is in a neutral position. This is compared to a second projected pen mark representing the change in transverse plane displacement once the foot is relaxed.

Notwithstanding the simplicity of this type of clinical test, due to limited obtainable outcome data there is a lack of understanding of how the information gained can be applied to the dynamic situation and more importantly be applied to foot pathology or dysfunction.

In acknowledgement of this criticism further work has emerged enhancing understanding of the static versus dynamic relationship. In one study McPoil and Cornwall (1996), static navicular height was the only measure out of 17 static tests included in the regression model, that was strongly associated with predicting dynamic maximum rearfoot pronation. The difference in navicular height between resting and neutral standing postures was the only test that was significantly able to predict maximum rearfoot pronation ($r = .42$, $r^2 = .17$ $p < .002$).

2.10.2 Dynamic navicular displacement

Since this earlier work, further research investigating the relationship between dynamic navicular movement and other parameters used in assessing foot function provides the bedrock for the current investigation.

Cornwall and McPoil (1999) were amongst the first to report evaluation of navicular drop in the dynamic situation. Results demonstrated concurrence with Brody's (Brody, 1982) reports on vertical displacement patterns in the static assessment study. Cornwall and McPoil (1999) concluded that the NDro test was a reliable and valid indicator of dynamic NDro. The same authors also noted a limitation to only observing vertical displacement as the results from their study demonstrated a significant mediolateral displacement of the navicular. The study (Cornwall & McPoil, 1999) also confirmed validation of the navicular height test originally proposed by Brody (1982). The authors conclude that static and

dynamic measures of the navicular bone serve as global indicators of rear foot and midfoot components of pronation and supination (Cornwall & McPoil, 1999).

Although the work by McPoil, Vicenzino, Cornwall, Collins, and Warren (2009) claims the results derived from the NDro test were valid, their work also highlighted a number of limitations to using a single static test to assess dynamic foot function.

More recent research has questioned the work of Brody (1982). Rathleff et al. (2012) replicated Brody's work as described in the original paper and compared this with dynamic data collected using two-dimensional video capture during treadmill walking. The authors (Rathleff et al., 2012) conclude that their data demonstrates a high correlational relationship, and is in agreement with Cornwall and McPoil (1999), however they also report a large variance around the line of best fit for NDro in comparison with NDro during heel strike in a dynamic situation. In 95% of the participants studied, a static navicular drop of 5mm corresponds to 3-9mm of dynamic navicular drop. Despite showing strong correlational relationships, static NDro does not in fact accurately describe the dynamic picture.

One possible reason for this is that movement at the navicular occurs in three body planes with the majority of movement being in the transverse and sagittal plane. Cornwall and McPoil (1999) report the timing of gait events as a significant finding of their data. In their study the timing of these variables was 47.8% (± 14.6) and 53.1% (± 10.2) of the stance phase duration (SPD) respectively. These values would represent approximately 29% and 32% of the entire gait cycle respectively.

These observations laid the foundation for further research observing the characteristics of NDri. The NDri test was originally proposed by Menz. (1998), and later reported on by Vinicombe, Raspovic, and Menz (2001). From this work it was established that NDri yielded more significant mediolateral displacement than the vertical displacement observed by the NDro test. The authors additionally reported on the repeatability of NDri and found it to be only moderately reliable with intratester intraclass correlation coefficients of 0.3 to 0.62. This added to the doubt cast on the reliability of static NDro to explain dynamic function of the midfoot and has led to the belief that dynamic measures are required to assess movement of the navicular during gait.

Further work assessing both NDro and NDri in static and dynamic situations has provided a more statistically detailed picture of the significance of these tests and the interpretation of the results used to describe foot posture characteristics (Christensen et al., 2014; Dicharry et al., 2009; Kappel et al., 2012; McPoil, Cornwall, Abeler, Devereaux, & Flood, 2013; McPoil et al., 2009; R. G. Nielsen et al., 2010; Rathleff et al., 2012; Spornndly-Nees, Dasberg, Nielsen, Boesen, & Langberg, 2011). Most recently, both dynamic navicular drift (DyNDri) and dynamic navicular drop (DyNDro) have been investigated following speculation surrounding the limitations of static assessment. Kothari et al. (2014) investigated and compared static and dynamic NDro and NDri, in a paediatric population demonstrating differing foot postures, using three-dimensional motion analysis.

Initial results report there was no significant difference between the mean values of DyNDro and NDro or between DyNDro and NDro (Pearson R of 0.71 (P.001)). Overall static and dynamic measures correlated well. However, in the foot posture analysis, while a strong correlation between NDri and NDro was seen in the neutral foot type, there was no such correlation in the pronated foot posture (Pearson's R of 0.18.).

There are no studies that have assessed the merits of navicular displacement (NDri or NDro) in participants with PTTD.

2.11 Summary

This literature review has identified that not only is there little or no consensus regarding current understanding of the aetiological make-up of posterior tibial tendon dysfunction, there also appears to be little consensus regarding the assessment of the condition, the terminology used to describe it, or the best approach to its management. These gaps in our understanding of this debilitating condition must be bridged if there is to be a streamlined approach to patient care. Although there is a plethora of research regarding treatments which relate to surgical intervention, the latest research suggests that early intervention with conservative treatment could be advantageous to patient mobility, and therefore ability to manage progression of the deformity on a daily basis. However, the crucial link here is early diagnosis. The existing prevalence studies have shown that this condition is poorly diagnosed. Therefore, any new research that could raise awareness among health care professionals, in order to aid early diagnosis and immediate

conservative treatment can only be viewed as a positive step forward. Podiatrists are in an ideal position to deliver this. The current prevalence studies suggest that many patients may have already progressed too far for conservative management because they have a late or missed diagnosis. Some GPs (general practitioners or family doctors) may also delay referral to orthopaedic teams, so as not to overburden the service, and may not refer to podiatry either, risking progression of the disorder and its subsequent sequela.

For this condition to be recognised as a significant musculoskeletal disorder, further work must be undertaken to establish a clearer understanding of etiological factors that affect progression. Furthermore, if podiatrists are going to be recognised for their work in the early diagnosis and provision of early conservative intervention, the profession must be ready to engage in the cutting edge research needed to establish and consolidate our current understanding of this incapacitating foot pathology. There needs to be consolidation of the current clinical practice arrangements for assessment of PTTD, and an understanding of the underpinning evidence for the current approaches to assessment.

The results from the studies included within this review have failed to clarify the interpretation of results and validity of current tests in the assessment of PTTD. It has yet to be established what effect foot type might have on the performance of a single heel rise, for example. Further investigation would be welcome to ascertain the precise mechanism involved in the single heel rise test. Additionally, further work to clarify the validity of the test would help to improve our understanding of the assessment methods used in this debilitating chronic condition. Similarly, there is much debate surrounding navicular displacement and the role it plays in the progression of PTTD.

Chapter 3: Background and context to the methodological basis of this study

3.1 The mixed methods approach in the assessment and diagnosis of PTTD

This chapter will detail the methodological basis for the thesis. It will explore the mixed methods approach and the blending of both quantitative and qualitative techniques in order to meet the aims and objectives set out in Chapter 1, and in so doing, answer the research questions posed in Section 1.4.

In recent years musculoskeletal (MSK) clinical practice has developed both in the field of podiatry and in other related allied health professional (AHP) roles such as physiotherapy. The restructuring of clinical roles for health workers in the UK resulted in a need for advanced clinical practice, and MSK practice is one of the areas that has seen significant growth.

Posterior Tibial Tendon Dysfunction (PTTD) is a musculoskeletal condition that significantly and detrimentally affects its sufferers. There is also evidence that suggests that diagnosis of the condition is poor among health care teams (Kohls-Gatzoulis, Angel, Singh, et al., 2004).

Despite clinical advancement regarding interventions and treatment outcomes for PTTD, epidemiological research suggests that PTTD is poorly diagnosed within the health care setting and many patients either receive a late or missed diagnosis or may not be receiving an appropriate intervention that could help reduce progression of the disease (Holmes & Mann, 1992; Kohls-Gatzoulis, Woods, Angel, & Singh, 2009a).

The stark contrast between the published quantitative research findings, producing evidence to assist clinicians to provide timely interventions for this disabling condition, and the unequivocal acknowledgement that timely diagnosis may be being missed, has produced a clinical dichotomy.

Some excellent quantitative studies have been published within the last decade, cataloguing best practice in terms of clinical interventions and outcomes (Houck et al., 2009a; Houck et al., 2008; Kulig et al., 2006; Kulig et al., 2009; Neville et al., 2009, 2010; Neville, Flemister, Tome, & Houck, 2007; Nielsen et al., 2011). Early conservative

intervention has demonstrated significant improvements in the quality of life regarding disability, function and pain.

All of this, however, may be of little consequence if PTTD is not being diagnosed early enough or if appropriate action is not being taken to assist onward referral for further advanced assessment and diagnosis (Birch, 2001; Blake, Anderson, & Ferguson, 1994; M. R. Edwards, Jack, & Singh, 2008; Kohls-Gatzoulis, Angel, & Singh, 2004; Kohls-Gatzoulis, Angel, et al., 2004b; Lake et al., 1999; Raikin et al., 2012; Simonsen et al., 2006; Singh et al., 2012).

What is clear is that PTTD is a disabling condition that, when diagnosed, can necessitate significant life style changes in the lives of patients. It is progressive, and will worsen if timely and informed diagnosis is not achieved. It is thus in patients' best interests for clinicians to understand what informs and shapes their clinical decision making when it comes to assessment and diagnosis of the condition. It is also appropriate to gauge how existing published assessment and diagnostic information is utilised in practice and how this aligns with empirical assessment and diagnostic data.

Much of the research conducted in the health care setting focusses on the biomedical model, and follows a deductive positivist methodology. However, the appropriateness of such an approach has been the subject of debate, some arguing that adherence to this epistemological stance may limit our ability to fully explore and understand multifarious facets of patient care (Jensen, 2007; Johnson, Onwuegbuzie, & Turner, 2007; Petty, Thomson, & Stew, 2012a, 2012b).

While it is acknowledged that the positivist approach brings much needed research, informing the efficacy of treatments and quantitative evaluations of patient outcomes (Shaw, Connelly, & Zecevic, 2010; van Griensven, Moore, & Hall, 2014), for this particular condition, positivism or post-positivism perhaps misses opportunities to fully explore how the approach to assessment and diagnosis has been shaped over time. Moreover, qualitative interpretivist approaches provide an opportunity to explore how the artistry of practice (Chan, 2014; Thomson, Petty, & Moore, 2014) aligns with the empirical quantitative data that informs both assessment and diagnosis of this condition.

Observations within specialist and non-specialist musculoskeletal (MSK) podiatry teams and multidisciplinary MSK teams have led to a number of different emergent observable approaches to the assessment and diagnosis of PTTD. This raises suspicion that there may be disparity between what clinicians perceive to be important in the assessment and diagnosis of this condition, how this aligns the findings of empirical evidence, and how this information is being embedded within daily practice.

The points raised here have led to the realisation that, in order to fully investigate the problem of late or missed diagnosis of PTTD, engagement with clinicians involved in the process must be exploited. This is in addition to, and not instead of, the gathering of empirical evidence to support interventions and provide measureable outcomes.

As previously mentioned, the efficacy of empirical evidence is unequivocal in terms of producing good treatment outcomes and demonstrable changes in the kinematic performance of patients with PTTD. However, whilst there is still evidence that the condition is poorly diagnosed and that many patients are receiving a late or delayed diagnosis, there is surely a case for exploring the opinions and beliefs of clinicians with regard to clinical reasoning and approaches to PTTD assessment and diagnosis.

In order to achieve this there is a need for a shift in thinking. Health care professionals have historically been aligned to the biomedical model, following the acceptance of the dominant positivist paradigm which produces the majority of the evidence base in medical fields. In this traditional hierarchy of research, randomised control studies are placed at the top providing the strongest form of evidence (Bartlett et al., 2006; Hadi, Alldred, Closs, & Briggs, 2013; van Griensven et al., 2014; Wisdom, Cavaleri, Onwuegbuzie, & Green, 2012). However, more recent work has led to the questioning of the status quo, recognising that this reductionist model falls short of fully exploring and explaining the complexity of patient centred care, and that it fails to fully explain the role of clinical reasoning and the more subtle nuances that are an integral part of being a clinician in practice (Bartlett et al., 2006; Giddings, 2006, 2007; Shaw et al., 2010).

This naturally suggests that the information gathered from empirical research may not be the only data that has helped form opinions and beliefs about certain conditions. There are many facets of knowledge acquired in and through practice. We may recognise some of them as being more important than others. Knowledge is gained via a wide range of resources and methods. For example, how to carry out an assessment test is deemed practical knowledge, which undoubtedly improves with practice, which is experiential knowledge, and may be informed by knowledge exchanged between peers and/or that gained from books and journal articles which is propositional knowledge. All of these forms of knowledge have been highlighted on the journey from novice to expert (Benner, 1984; Eraut, 1994; Schön, 1991).

It stands to reason therefore that, in order to fully appreciate all aspects of a particular medical condition or clinical pathology, a wider and broader ranging approach is required. One way to appreciate the epistemological differences is to engage with a methodology that allows the researcher the freedom to explore both the positivist deductive elements of a clinical challenge, but also to embrace the interpretivist inductive aspects that may be influencing the decision making and clinical reasoning of a clinical group or individual clinicians in practice.

Pressure on clinicians to deliver evidenced based care with measureable outcomes and to be accountable for the outcomes in practice has led to a watershed in terms of challenging the belief structures associated with a purely positivist approach. Clinicians working at an advanced level have acquired knowledge from a wide and varied heterogeneous resource. This means that while their opinions and beliefs may have been influenced and informed by empirical data, this does not represent the totality of what has contributed to their expert status as a practitioner (I. Edwards & Richardson, 2008; Giddings, 2006; Higgs & Titchen, 1995; Morgan, 2007; Tashakkori & Creswell, 2007) .

Therein lies the essence of a mixed methods approach to exploring and researching health related clinical conditions. Still in its embryonic stage of development this paradigm remains controversial in its epistemological underpinning, being neither inductive nor deductive. It seems, therefore, necessary to spend some time discussing the potential controversies, in order to then explain how this methodology has been adopted

for this particular study. What follows is an exploration of some of the key literature surrounding a mixed methods approach.

Defining mixed methods – the third research paradigm – has resulted in significant debate among research scholars, and despite attempts to produce a consistent definition, there remains disquiet. Johnson et al. (2007) provided key findings from work conducted in the pursuit of a definition, seeking interpretations from nine experts in the field of mixed methods research. What emerged from the analysis was a surprising array of definitions and understandings, echoing the findings of other authors seeking to disseminate clinical evidence arising from mixed methods studies. For example, Lewin, Glenton, and Oxman (2009) attempted to investigate the use of qualitative methods alongside randomised control trials. While the emphasis of the study was not explicit about exploring mixed methodologies, the outcome of the study pointed toward unclear reporting for both study design and data analysis, where qualitative studies were used alongside randomised control trials (RCTs). A further interesting point relates to integration of the qualitative findings cited in this study. Out of the 100 trials included for review, 30 had qualitative studies associated with them, and of these, 19 were published. From the 19, however, only two reported explicitly that a mixed methods approach had been employed. The authors concluded that most of the qualitative studies included had significant methodological shortcomings.

Because mixed methods research crosses two established and accepted existing research paradigms, depending on the predominant epistemological position of the researcher there may be unconscious bias in the reporting and critical evaluation of either the qualitative or quantitative methods employed. Johnson et al. (2007) alluded to this, describing the spectrum from qualitative to quantitative approaches as a continuum. The researcher's "primary home" on this continuum will influence the emphasis placed on a particular methodological approach. The authors argue for a contingency theory of research where researchers may need to adopt a "second home" should the nature of the research in question benefit from such a visit. Depending on where the primary home is, the researcher may be qualitative or quantitative mixed methods dominant. This is a point highlighted in various guises by others, either advocating the mixed methods approach, or acknowledging that quantitative and qualitative methods existing

concurrently within one study can add to the richness of the data and subsequent analysis (Johnson & Onwuegbuzie, 2004; Mays & Pope, 1995, 2000; Thomson et al., 2014; van Griensven et al., 2014).

Some authors conclude that we currently are in a three methodological or research paradigm world, with quantitative, qualitative, and mixed methods research all thriving and coexisting (Johnson et al., 2007).

Mixed methods research, while being embraced within the nursing literature, is scarce within the therapies and allied health professional research. One recent study, however, has demonstrated the benefits that mixed methods research can bring. Rowe et al. (2012) conducted a mixed methods study to enhance the understanding of treatment interventions for Achilles tendinopathy among physiotherapists. The study combined a literature review and data from semi-structured interviews to highlight the potential problems with clinicians using systematic reviews as their main source of information when deciding on best practice approaches to the treatment of pathologies commonly seen in practice. It highlighted clinical reasoning as key to successful outcomes in clinical practice. Due to the very tight criteria applied to RCTs, this clinical reasoning is often omitted when presenting the outcomes of such studies. In fact, mixed methods research would not be included in a true systematic review that considered RCTs alone. This research has placed importance on the individual tailoring that often occurs in clinical practice in order to achieve better outcomes for patients. This tailoring was the result of a combination of clinical experience and clinical reasoning that led to adaptations and compromises made to strict protocols in order to accommodate individual patient differences.

Similarly, a study by Hendry et al. (2013) utilises the mixed methods approach in determining the level of foot care services provided for patients with rheumatoid arthritis in Sydney, Australia. This study conducted research using interviews with patients and combined this with clinical assessment data, demographic data and questionnaire based quality of life data. Again this type of study would not be classed as the highest level research, however the outcome of such a study has the potential to significantly influence health care provision to patients within the demographic area and beyond.

Intervention studies are plentiful in comparison to the paucity of research investigating possible reasons for the poor diagnostic profile of PTTD. What follows in Chapters 4, 5, and 6 is a blended approach, which exploits both inductive and deductive reasoning in order to answer the research questions highlighted in Chapter 1, Sections 1.1-1.4. Each of the three chapters is written as a 'stand alone' study, with its own discussion section. The summative discussion in Chapter 7 brings together the main elements of each discussion section. Chapter 8 then discusses how the data presented can influence and shape clinical protocol development, and the implications for clinical management of PTTD in light of new information. Much of the work presented hereafter is novel (the subject matter has never been investigated or reported upon in this way before), therefore the findings are also novel and bring a new perspective to our understanding of the assessment and diagnosis of PTTD.

Chapter 4: Examining the opinions and beliefs of Health Care Professionals surrounding the assessment and diagnosis of PTTD

Aspects of this chapter have been published:

Durrant, B., Chockalingam, N., Hashmi, F., & Richards, P. J. (2014). Abstracts. *Clinical Anatomy*, 27(2), 262-273. doi:10.1002/ca.22304.

Durrant, B., Chockalingam, N., Morriss Roberts, C. (2016). Assessment and Diagnosis of Posterior Tibial Tendon Dysfunction: Do We Share the Same Opinions and Beliefs? *Journal of the American Podiatric Medical Association*. doi:10.7547/14-122.1.

4.1 Introduction

Posterior Tibial Tendon Dysfunction (PTTD) is a disabling pathological flat foot disorder which can significantly inhibit the ability to mobilize independently and maintain activities of daily living. Despite this, there has been little work in the area of assessment and diagnosis and even less regarding the prevalence and epidemiology of this condition (Holmes & Mann, 1992).

Although the understanding of PTTD has improved over recent years with a number of publications raising awareness of the condition (Chhabra et al., 2011; Durrant, Chockalingam, & Hashmi, 2011; Kulig et al., 2009; Neville et al., 2009; Singh et al., 2012; J. Tome, D. A. Nawoczinski, et al., 2006; Watanabe et al., 2013), several gaps in knowledge remain. These gaps relate to diagnostic and assessment procedures. This has led to uncertainty amongst health care teams regarding the best approach to adopt when identifying this condition. The working practices of health care professionals may also have an impact upon the approaches to assessment and diagnosis. For example, podiatrists often work in isolation within community clinics and this lack of interdisciplinary interaction could lead to individual approaches to PTTD management. Additionally, lack of awareness among health care professionals, and of interdisciplinary and multidisciplinary approaches to the assessment and diagnosis of the condition, contribute to the reported poor diagnostic profile of affected patients (Holmes & Mann, 1992).

With an estimated 3.3% of women over the age of 40 affected by this condition (Kohls-Gatzoulis, Woods, Angel, & Singh, 2009b) and with many of the positively identified PTTD sufferers not receiving any specialist care, further research is required. The authors postulate that in the absence of a validated assessment and diagnostic protocol, the factors mentioned above are enhanced. Previous studies suggest that patients only receive a diagnosis once their mobility and independence has been significantly affected (Holmes & Mann, 1992; Kohls-Gatzoulis et al., 2009b).

In the recent past there have been a number of publications detailing the benefits of the conservative management of PTTD. Although this evidence assumes an early presentation of the condition, the results are unequivocal in terms of the therapeutic benefits of conservative intervention (Neville et al., 2010; C. Neville, A. S. Flemister, & J. R. Houck,

2009; Singh et al., 2012; Tome, Nawoczenski, Flemister, & Houk, 2006). However, given that there is also evidence that suggests that patients are not receiving timely diagnoses and that generally the diagnosis of this condition by members of health care teams is poor in the UK, this would suggest this optimal window for therapeutic interventions may be lost (Holmes & Mann, 1992; Kulig et al., 2009; Singh et al., 2012).

Therefore, the main aim of this study was:

1. To investigate the views and opinions of health care professionals who encounter PTTD in their clinical practice in order to explore levels of agreement in the areas of assessment and diagnosis.

In so doing, two of the three principal research questions will be partially addressed (see Section 1.4):

1. Is there disconnect between interdisciplinary opinions and beliefs surrounding the assessment and timely diagnosis of PTTD?
2. What contribution does interdisciplinary consultation make to the exploration of assessment approaches for PTTD with a view to clinical protocol development?

4.2 Methods

A two phase sequential mixed methods design combining questionnaire survey analysis and focus group interview was employed (Kroll & Morris, 2009). The analysis and subsequent richness that results from this type of analysis is well suited to studies seeking to combine both inductive and deductive methodologies (Beatty & Willis, 2007; Brace, 2004; Kroll & Morris, 2009; Tashakkori & Creswell, 2007; Wisdom et al., 2012).

Focus group participants were required to give consent to the recording of the focus group discussions and transcription of the recording and subsequent dissemination of the findings. The method was executed in two phases.

4.2.1 Phase 1

Since there is no validated questionnaire available to meet the aims of this study a web based survey questionnaire suitable for exploring the research question was developed. The questionnaire was designed utilising published literature to help inform the topic areas. Next, in accordance with questionnaire design guidelines (Beatty & Willis, 2007),

the main researcher and an experienced academic researcher with expertise in this area, reviewed the content derived from the literature. Finally, the questionnaire was piloted on a small sample (n=5) of colleagues with experience of qualitative questionnaire based research studies. Cognitive debriefing was used to apply a consistent method to evaluate the content of the questionnaire (Braun & Clarke, 2006). This process involved speaking individually to pilot participants about the completion of the questionnaire. Responses were then collated from all 5 pilot participants. Amendments were made to the questionnaire where the responses were consistent in showing that there was confusion, lack of clarity and meaning, or where pilot participants felt that the essence of the question was not clear. The draft questionnaire was modified to reflect these comments, leading to the final design which consisted of 29 questions. The questions were intended to elicit responses in five main areas pertinent to the diagnosis of PTTD. These were: key clinical signs and symptoms; imaging; assessment; impact on quality of life; and patient reported symptoms.

Permission was sought to circulate the questionnaire from professional groups, which included the Chartered Society of Physiotherapists and the Society of Chiropractors and Podiatrists. The British Orthopaedic Foot and Ankle Society were also contacted to seek permission to circulate the questionnaire, however the committee declined the application, and hence this group were not included in the study. Extended scope musculoskeletal (MSK) physiotherapists, specialist MSK podiatrists and podiatric foot and ankle surgeons were contacted directly through their respective online professional groups. Approximately 500 questionnaires were distributed. A precise figure cannot be provided due to the chain referral sampling, or snowball sampling (Biernacki & Waldorf, 1981; Penrod, Preston, Cain, & Starks, 2003), that may have taken place within these specialist clinical groups.

4.2.2 Phase 2

The focus group was assembled in order to better understand the questionnaire responses. The aim of this study is to improve the understanding of why PTTD is poorly diagnosed. As this is potentially a sensitive area to explore, using focus groups to further 'unpack' questionnaire responses is one way of accessing undiscovered conversations and the 'hard to reach' (Barbour, 2007). See section 4.7 for a fuller explanation and discussion on focus group inclusion.

Once the questionnaire data had been collated the lead researcher (BD) completed an initial analysis of key word and percentage responses. Agreement and disagreement surrounding a number of key areas were found both within and between professional groups. This provided a framework for the focus group to identify the main areas where there was an obvious lack of agreement. The focus group attendees were four healthcare professionals with specialist MSK expertise who were likely to frequently encounter this condition. The professional background of the participants was as follows:

- One foot and ankle surgeon based in a secondary care setting (9 years' experience).
- Two MSK specialist podiatrists. Both hold leadership posts in the field of foot and ankle MSK pathology in both primary and secondary care settings (each with 10 years' experience).
- One MSK physiotherapist, who has worked both in hospital and primary care settings (15 years' experience).

A second physiotherapist was recruited to participate but was unable to attend on the day. Since each of the professional groups who were recruited to participate in the questionnaire survey were represented, it was decided to continue with the focus group, given the difficulty of bringing groups of professionals together, and the time that had been taken out of busy clinical schedules.

The focus group was facilitated by an independent expert, experienced in running workshops and group participation activities. The lead researcher was present to listen to the discussions and take field notes. The meeting lasted for 2 hours and discussion was recorded. The recording was then transcribed verbatim for further thematic analysis. See Section 4.6 and 4.11 for more information on facilitation and data transcribing. The decision to use an independent facilitator gave the researcher an opportunity to take valuable field notes, which formed the embryonic stages of the coding process, and was therefore deemed worthwhile and appropriate.

4.3 Data analysis

In order to demonstrate trustworthiness and rigor of the data analysis, two types of triangulation (see Section 4.11.3 and 4.12 for a full justification surrounding triangulation) are offered following the method outlined by Patton (2014). First, to demonstrate the credibility of the findings, and by extension the trustworthiness of the analysis, integrative mixed methods qualitative and quantitative triangulation was adopted. This method, explained by Patton (2014), involves employing both qualitative and quantitative methods to analyse a data set. For the process of triangulation three methods of analysis were used to analyse the questionnaire and focus group responses. These were: thematic analysis conducted on the data collected at the focus group meeting; statistical analysis, both descriptive and inferential, conducted on the closed question responses of the questionnaire; and content analysis, conducted on the data collected from the open ended question responses to the questionnaire.

Second, investigator triangulation (Patton, 2014) was also conducted. This approach involves three researchers analysing the same data set, and collaboration on the findings of each. This was primarily to ensure that researcher bias did not introduce a limited perspective when conducting the analysis and interpreting the results.

4.4 Open ended responses

Content analysis was employed as the preferred method for analysing the open ended responses. Chapter 3 has explained the epistemological positioning of content analysis and why this type of analysis is preferred for the data presented here. A method similar to that outlined by Krippendorff (2012) was employed to conduct the content analysis arm of this study.

The questionnaire was divided into open and closed questions, and distributed electronically by an online survey tool called Qualtrics. This software (Qualtrics LLC 2015, Provo, Utah) allows the creation and distribution of an online survey or questionnaire via an electronic link that is circulated through an email network. The permissions granted by The Musculoskeletal Association of Chartered Physiotherapists, the Faculty of Podiatric Surgery, College of Podiatry, and the Musculoskeletal Alumni Network of Staffordshire University, allowed the distribution of the questionnaire to membership email accounts of specialist MSK professionals whose email contact details were held on a database owned by the professional bodies named above. To anonymise this process, the

researcher sent the link to the site administrators, who then distributed it to the membership of their respective organisation. The questionnaire was then completed online by individual participants and submitted anonymously to the Qualtrics database. From here, the researcher was able to access the completed questionnaires using an online, password protected account.

The open ended questions provided short answer responses. In total there were ten open ended questions. As with many of the qualitative approaches to analysis, the first process is to become familiar with the content. This involved reading, and re-reading the questionnaire responses. For each of the responses to each of the questions a compilation of responses was arranged in one continuous document. This meant that the researcher was able to read and re-read the responses collectively, which helped with familiarity. Next, the researcher highlighted words that were repeatedly reported. A scanned example of this process can be seen in Appendix 12.1.

Having read and re-read the responses to each question, and highlighted all the key words, one question stood out as the core question that was linked in some way to all the other questions. Following the literature surrounding content analysis, this question was used as the 'core sampling unit'.

The initial analysis used the sampling unit taken from the responses to a core question posed to respondents. Krippendorff (2012) p.99) describes sampling units as: "Units that are distinguished for selective inclusion in an analysis". Question 27 asked participants what key features should be included in a staging/assessment criteria. Participants were advised that they could list as many items as they felt necessary.

For each keyword response generated, a mind map was constructed to illustrate other words and phrases surrounding the key word. See Appendix 12.3 for detail of the mind maps for both the sampling units and the context coding units (described in Section 4.11 below).

The same process of identification of key words and generation of mind maps to reflect the context of the words that were selected was repeated for the remaining responses. The result of this process led to a series of coding units, which have been named context coding units in line with the definition provided by Krippendorff (2012 p.101), where:

“Context units are units of textual matter that set limits on the information to be considered in the description of the recording units”.

On completion of these two processes, the core sampling unit was mapped to the context coding units. Once the sampling units and the context coding units were mapped, a single mind map was produced to illustrate the resulting mapped codes that are discussed in the next section, 4.5-4.11 and figure 11.

4.5 Closed question responses

The closed question responses provided data suitable for quantitative statistical analysis. The responses from these questions were analysed utilising two statistical procedures. The procedure produced descriptive statistics whereby percentage response rates were collected (see Section 4.9, table 2). The second procedure required inferential statistics to convey levels of inter and intra professional agreement to the responses given. For this, the IBM Statistics Package for the Social Sciences (SPSS), version 21, was utilised. The within group results were analysed using Kendal's coefficient of concordance and the between group agreement was analysed using Cohen's kappa statistic. Results were considered to demonstrate substantial agreement if they had a Kappa statistic of between 0.61-1, and for Kendall's W a result of between 0.7-1 was considered a strong level of agreement (see Section 4.9 and 4.9.1).

4.6 Focus group

The transcribed focus group data underwent thematic analysis following a method similar to that outlined in the literature (Barbour, 2007; Braun & Clarke, 2006). This model of analysis was employed as it offers a flexible approach to qualitative data analysis, and is a widely used method employed to analyse data collected from a variety of mediums including interviews and focus groups. It allows the organisation of the data which in turn describes the data set in rich detail using the generated themes which are exposed through the process. Embedded in critical realist epistemological positioning; thematic analysis aims to enable the researcher to uncover the reality, experiences and meanings of the key issue under investigation.

The data was coded in accordance with the method proposed by Braun and Clarke (2006). This part of the analysis was conducted by the researcher. The initial coding was verified by an independent researcher experienced in qualitative research, who was able to review the codes and initial themes.

The type of thematic analysis that was undertaken utilised an inductive approach. That is to say that the researcher was not trying to 'fit' the data around a specific research question (Barbour, 2007; Braun & Clarke, 2006; Shaw et al., 2010). In the previous section

(4.5), it was highlighted that the initial responses from the closed questions provided the key areas with which to begin the focus group discussions. Moreover, this approach meant that there was flexibility within the coding method since the researcher was not trying to code with reference to a specific coding framework, as might have been the case if a deductive approach had been adopted. This approach to the analysis was appropriate for this data set, since there is no published data with which to compare the coded data.

The first part of the data analysis process began with reading and re-reading the transcript generated from the focus group meeting. This enabled the researcher to become familiar with the content of the transcribed data. This was especially important for the coding process in this study, as the data was transcribed by a third party. This point has been discussed and the researcher's position justified in Chapter 3, however in order to minimise the impact of third party transcription and to enhance the familiarisation process, the researcher began to make notes in the margin of the transcript, highlighting points that had been made that linked to other parts of the transcript. Although the transcript was typed and printed for the analysis the researcher was also able to listen to the audio recording. This allowed the researcher to hear the inflection in the voice of the participant, which helped with the initial note taking, and helped to immerse the listener in the data. These initial notes were aligned with the field notes taken at the focus group meeting. This process was repeated several times until the researcher had a sense that the data was familiar and that the flow of the transcript was known.

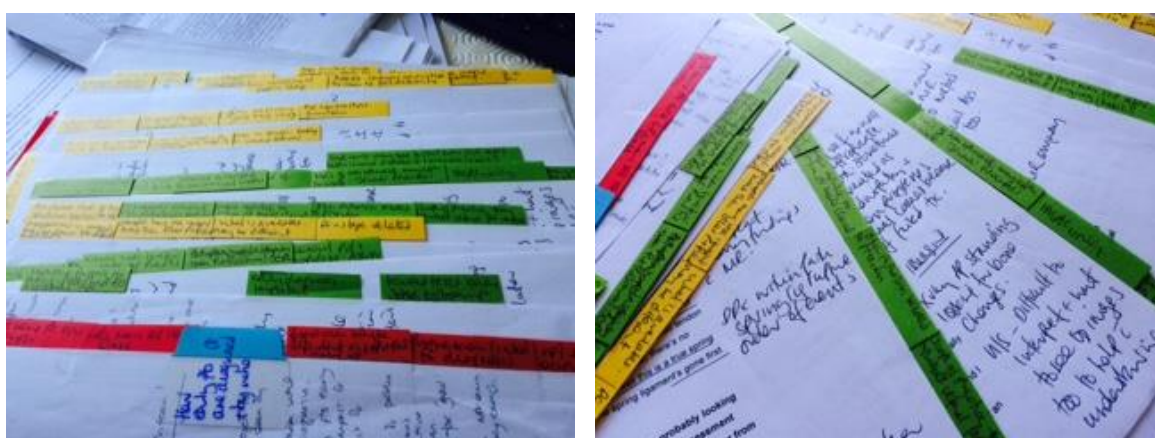


Figure 3: The process of tabulation.

Next, the initial coding process began. The researcher went through the entire script and used tabulated labels to further expand the initial notes made at the reading stage. These labelled 'tabs' identified the initial codes. Once the initial codes were identified, the researcher read through the script again and grouped the codes into sub codes or topics. This was achieved by writing the grouped themes onto 'flip cards', so that the assembled cards in each group could then be considered as individual items.



Figure 4: The process of 'flip card' coding.

From this the researcher could move codes under another heading, if deemed more appropriate, or add additional codes from other headings. The final arrangement of codes and sub codes were then organised according to the thematic content of the codes. What resulted was a series of themes that the researcher had identified through the coding and sub coding of the data. The process was inductive, so it was possible to move the data around until there was a natural 'resting place' for each set of codes and sub codes.

Where there was similarity between themes taken from the codes and sub codes, amalgamation of some recurring or similar codes and initial themes provided a more manageable number of themes that would later be discussed. An example of this was where imaging, assessment tests and tests related to diagnosis, became amalgamated in the data analysis to provide the final theme 'scope of practice'. This process of refinement was the final stage of the thematic analysis. From this arm of the study 3 themes were

defined for the next stage of the process. These are defined and discussed in the results section.

4.7 Results

4.7.1 Questionnaire survey results

From the 500 potential participants contacted, approximately 158 completed questionnaires were received, representing an approximate return rate of 31%. Due to the small number of responses from foot and ankle surgeons, these were not included within the statistical analysis; however, their comments are included in the qualitative analysis and subsequent results.

Table 1: Demographics of participants.

	MSK physiotherapists (n=86)**	MSK podiatrists (n=60)**	Podiatric foot and ankle surgeons (=12)**
*Practice experience	28	36	28
Sex M/F	48%(M) 52%(F)	61%(M) 36%(F)	95%(M) 5%(F)
Age range	28-54	29-57	28-47

**= total overall number of respondents

*= mean maximum length of time in specialist practice in years

4.7.2 Closed question responses

Table 2: Podiatry and Physiotherapy responses to closed questions.

= Podiatry = Physiotherapy

Q.2 In your experience do you consider weight-bearing and/or gait assessment essential to the diagnosis of PTTD?				
Answer	Response (n)	%	Response (n)	%
Yes	38	97%	47	96%
No	1	3%	2	4%
Total	39	100%	49	100%
Q.4 Do you think that the limited mobility experienced by patients with PTTD notably affects their quality of life?				
Answer	Response	%	Response	%
Yes	38	97%	44	90%
No	0	0%	0	0%
Don't know	1	3%	5	10%
Total	39	100%	49	100%
Q.5 Is imaging an essential requirement for the appropriate diagnosis of PTTD?				
Answer	Response	%	Response	%
Strongly disagree	3	6%	4	7%
Disagree	24	51%	15	28%
Don't know	0	0%	7	13%
Agree	9	19%	14	26%

Strongly agree	7	15%	3	6%
Neither agree nor disagree	4	9%	11	20%
Total	47	100%	54	100%
Q6. Is MRI preferred over diagnostic ultrasound to confirm the diagnosis of PTTD?				
Answer	Response	%	Response	%
Strongly disagree	5	11%	2	4%
Disagree	18	38%	20	38%
Don't know	6	13%	11	21%
Agree	9	19%	6	11%
Strongly agree	3	6%	2	4%
Neither agree nor disagree	6	13%	12	23%
Total	47	100%	53	100%
Q7. In your opinion do you believe a staging criteria (such as the Johnson and Strom criteria) is important in the assessment and diagnosis of PTTD?				
Answer	Response	%	Response	%
Not at all important	0	0%	1	2%
Unimportant	3	6%	3	6%
Don't know	6	13%	24	46%
Important	35	74%	19	37%
Very important	3	6%	5	10%
Total	47	100%	52	100%

Q8. In your experience do you think that the diagnosis of this condition can be improved?				
Answer	Response	%	Response	%
Yes	38	90%	48	98%
No	4	10%	1	2%
Total	42	100%	49	100%
Q10. Evidence suggests that PTTD can be treated successfully with conservative intervention. Please indicate below your agreement with this statement.				
Answer	Response	%	Response	%
Strongly disagree	2	5%	3	6%
Disagree	2	5%	1	2%
Don't know	0	0%	2	4%
Agree	17	44%	38	78%
Strongly agree	15	38%	5	10%
Neither agree nor disagree	3	8%	0	0
Total	39	100%	49	100%
Q11. Do you believe that patients' symptoms may improve over time without any intervention?				
Answer	Response	%	Response	%
Very unlikely	13	33%	9	18%
Unlikely	22	56%	30	61%
Don't know	1	3%	6	12%
Likely	2	5%	4	8%
Very likely	1	3%	0	0%

Total	39	100%	49	100%
Q13. In your opinion what is the predominant age range for presentation with PTTD? (Tick as many as appropriate.)				
Answer	Response	%	Response	%
Under 20	0	0%	3	5%
20-40	9	17%	32	53%
40-60	42	81%	33	55%
Over 60	17	33%	8	13%
Q16. Do you think that PTTD progresses in a predictable way?				
Answer	Response	%	Response	%
Yes	23	50%	14	30%
No	5	11%	8	17%
Variable	19	41%	26	55%
Q17. In your experience is the prevalence of PTTD highest in				
Answer	Response	%	Response	%
Males	0	0%	9	16%
Females	37	77%	27	48%
About equal	11	23%	20	36%
Total	48	100%	56	100%
Q19. Do you believe x-ray is useful to confirm diagnosis of PTTD?				
Answer	Response	%	Response	%
Very useful	0	0%	1	2%
Useful	7	16%	5	10%
Not useful	29	66%	32	67%

Useless	8	18%	10	21%
Total	44	100%	48	100%

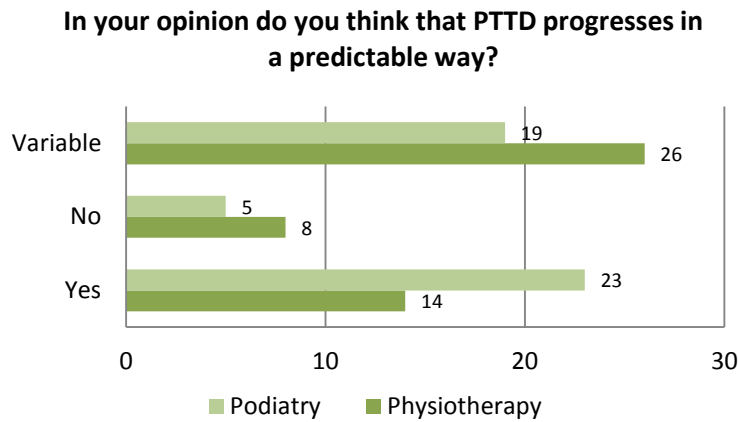
Q26. In your opinion, from the initial contact with a health care professional, how long, on average do you think it takes to confirm a diagnosis of PTTD?

Answer	Response	%	Response	%
1 week	10	25%	10	26%
2-4 weeks	9	23%	12	31%
1-2 months	9	23%	6	15%
3-4 months	7	18%	6	15%
4-6 months	2	5%	3	8%
Over 6 months	3	8%	2	5%
Total	40	100%	39	100%

Q28. In your experience do you think a non-weight-bearing assessment is essential to the diagnosis of PTTD?

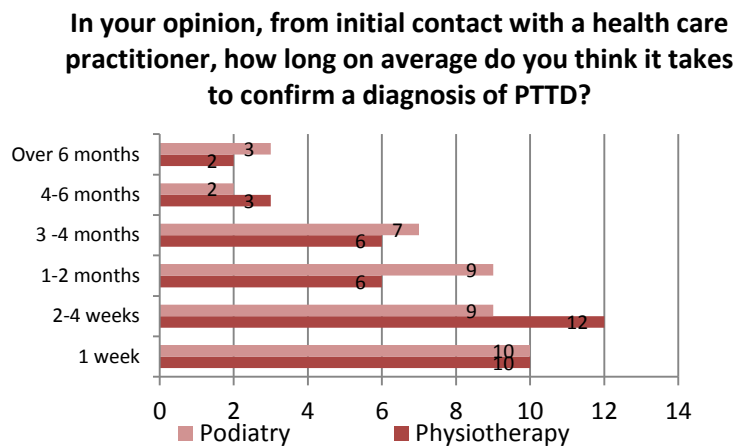
Answer	Response	%	Response	%
Yes	36	92%	41	84%
No	3	8%	5	10%
Don't know	0	0%	3	6%
Total	39	100%	49	100%

4.7.3 Figures illustrating inter and intra professional levels of agreement arising from the closed questionnaire responses.



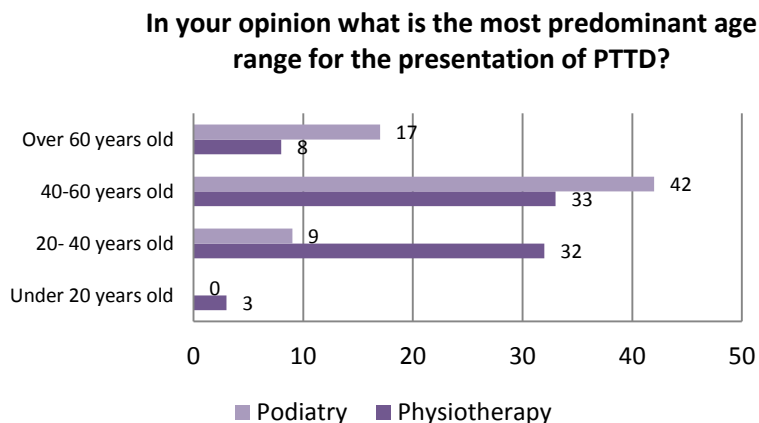
$\kappa = 0.527$ ($P < .001$),
podiatric medicine $W = 0.121$ ($P < .003$), and
physiotherapy $W = 0.101$ ($P < .008$).

Figure 5: Bar graph illustrating closed question responses



$\kappa = 0.874$ ($P < .001$),
podiatric medicine $W = 0.041$ ($P = 0.197$),
and physiotherapy $W = 0.060$ ($P = .04$).

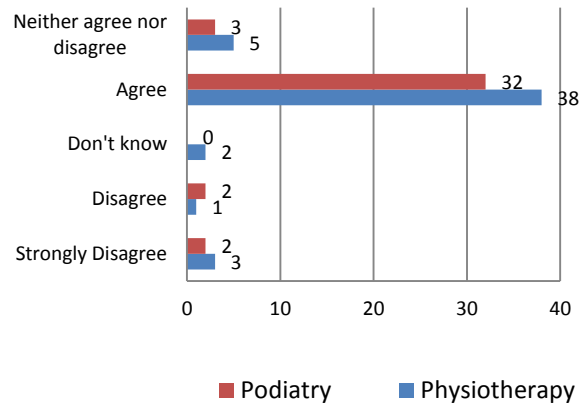
Figure 6: Bar graph illustrating closed question responses.



$\kappa = 0.054$ ($P < 0.419$), podiatric
medicine $W = 0.297$ ($P < .01$),
and physiotherapy $W = 0.217$ ($P < .01$).

Figure 7: Bar graph illustrating closed question responses.

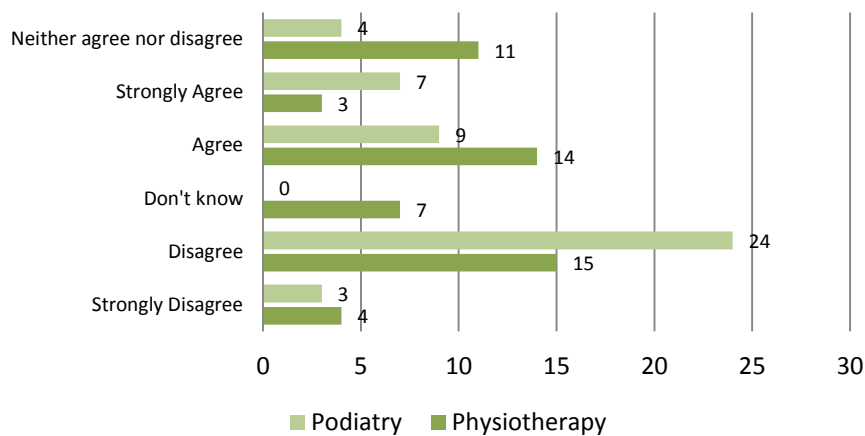
Evidence suggests that TPTD can be successfully managed with conservative intervention. Please indicate your agreement.



$\kappa = 0.62$ Podiatric medicine
 $W=0.586 (P<0.000)$
 Physiotherapy
 $W=0.522 (P<0.000)$

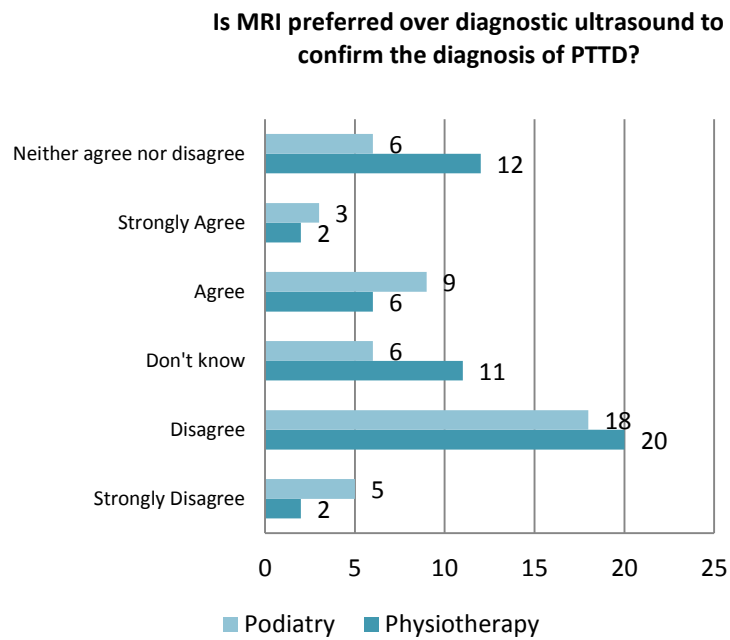
Figure 8: Bar graph illustrating closed question responses.

Is imaging an essential requirement for the assessment and diagnosis of TPTD?



$\kappa = 0.593 (P < .001)$,
 podiatric medicine
 $W = 0.091 (P < .01)$,
 and physiotherapy
 $W = 0.056 (P < .008)$.

Figure 9: Bar graph illustrating closed question responses.



$\kappa = 0.748$ ($P < .001$), podiatric medicine $W = 0.076$ ($P < .003$), and physiotherapy $W = 0.103$ ($P < .001$).

Figure 10: Bar graph illustrating closed question responses.

4.7.4 Open ended question responses

Figure 11 shows summarised data and analysis, demonstrating how the core question sampling units link to the mind maps representing the context coding units, and which responses were subsequently included in the discussion section.

The core question asked respondents what key features they thought should be included in an assessment or staging criteria. When asked how useful such a staging criteria was 47% of physiotherapy respondents and 80% of podiatry respondents thought such a tool was either important or very important. The content analysis in response to the core question sampling unit, in terms of the number of times a particular phrase or word was mentioned, are displayed in the table below.

Table 3: Key word responses from initial core sampling unit question.

Key word ➡								
Number of times mentioned ↓	Ligament	Foot posture	Heel rise	Imaging	Function	Swelling	Pain	Pronation
Podiatry responses (n=45)	5 (11%)	12 (26%)	17 (37%)	14 (31%)	8 (18%)	7 (15%)	25 (55%)	1 (2%)
Physiotherapy responses (n=49)	0	6 (12%)	10 (20%)	4 (8%)	18 (37%)	9 (18%)	27 (55%)	3 (6%)

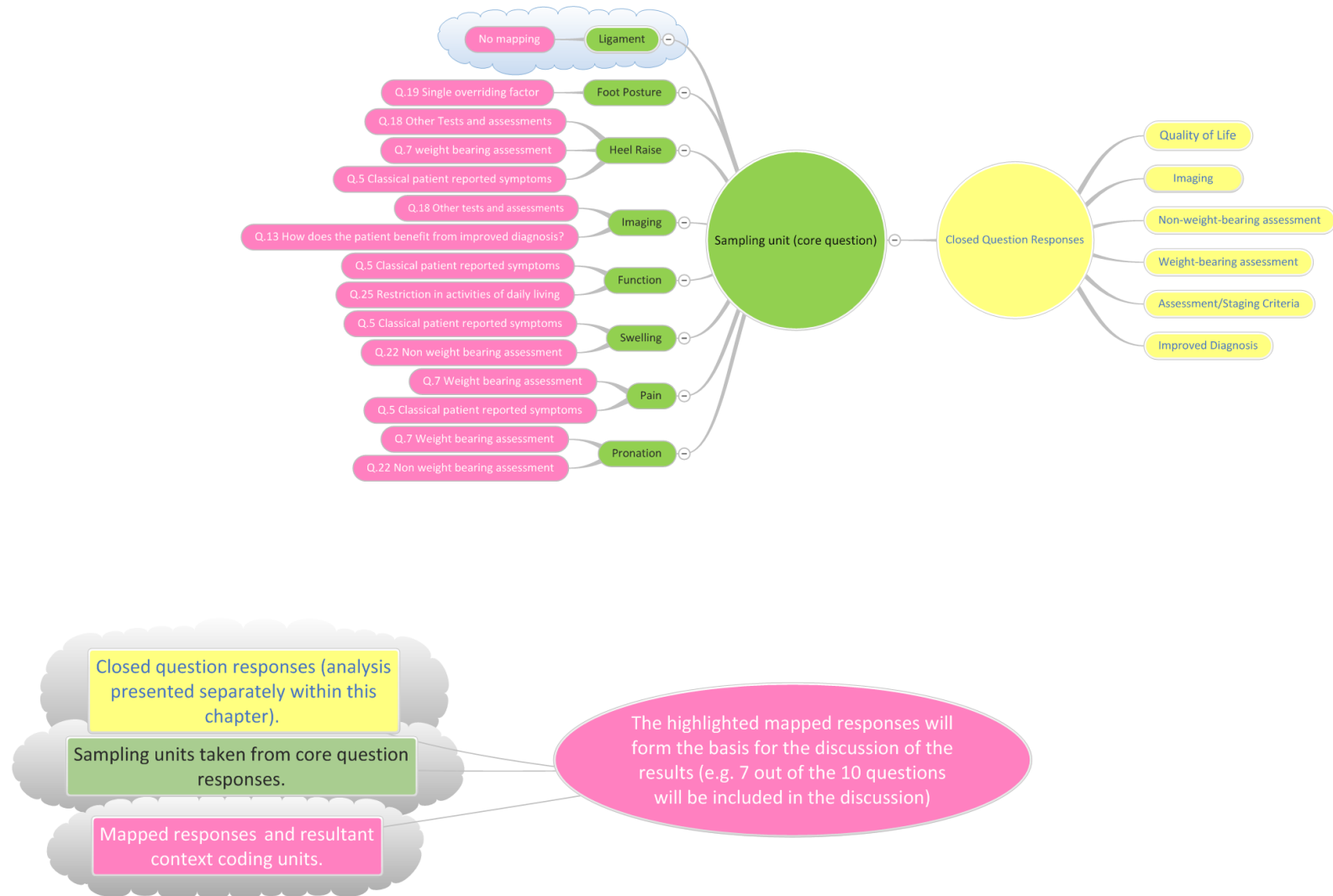


Figure 11: Mind map illustrating how the closed questions were mapped to the core question sampling unit and how these responses mapped to the context codes for the remaining data providing the final map of the analysis and a basis for the discussion.

4.7.5 Focus group results

Through a process of refinement of the initial codes and sub codes (see Section 4.3) 3 final themes were derived. These were i) resource implications, ii) scope of practice, and iii) clinical awareness of the condition.

The focus group data analysis is summarised and presented in relation to the 3 themes' as follows (see Appendix 12.2 for full transcript of the focus group meeting).

4.7.6 Resource implications

Throughout the focus group discussions there was a repetitive commentary that highlighted difficulties and restrictions and challenged the desire to provide "best practice". This was especially apparent when diagnosis of the condition were debated.

"... I think as a gold standard of treatment that's probably it, where you have a podiatrist and a surgeon sitting next to each other and you say yes I think that's tib post, and you ultrasound it and you're good at it. I don't have that facility on my clinic." (Podiatrist)

"... We've only just recently had MRI, so we've relied hugely on ultrasound [pause]. We now have MRI ability and we probably would use it for those where [pause] perhaps where the ultrasonographer has suggested MRI if they consider a tear is present." (Podiatrist)

For primary or community based care, access to MRI was limited for many services. Some extended scope practitioners (ESP) now have a direct access referral service; however, this is not mainstream practice for many departments. Although all of the participants were clinicians encountering this condition on a regular basis, there were mixed experiences when it came to imaging for the diagnosis of PTTD.

4.7.7 Scope of practice

There was a recurrent theme throughout the discussions which suggested that the variable experience and the scope of practice of clinical staff are, in part, responsible for the reported paucity in the timely diagnosis of the condition.

“... a lot of the early stages, are probably seen within the GP practice, so by the time we get them they tend to be quite a long way down the road and I think that’s possibly where some of the problems lie.” (Podiatrist)

“... I think it depends where they are seen [pause]. I think possibly in private practice is where sometimes these patients are poorly managed [pause], perhaps because they (sic) don’t have the knowledge that they think they have and don’t recognise that they need to move a bit faster and that they may need to refer on.”(Physiotherapist)

In addition, it was apparent that perhaps the differences in the approaches were not just down to a lack of understanding about the condition, but may also be reflective of the fact that different health care practitioners will practice in a way that compliments and supports the scope of practice for their particular discipline. This was the case for clinical reasoning and clinical decision making and when planning the care of the patient.

“... I suspect it’s just different health professions looking at things from different perspectives. So I should imagine surgeons are looking at the MRI scan every time and I suspect maybe on the podiatric side you’re looking more at biomechanical function of the tendon, so it may just be the different way people are looking at it, and where their background is ...” (Foot and ankle surgeon).

Therefore, although clinicians may work alongside each other in practice, shared decision making is not necessarily advocated or easily integrated into daily practice.

4.7.8 Clinical awareness of the condition

There were strong opinions from all members of the group relating to the lack of awareness of the condition which, it was suggested, contributed to the poor reported diagnosis and management of the condition.

“... I think there’s a widespread ignorance about this condition [pause] so a lot of people won’t know much about it. There needs to be a dissemination of information that this is a true pathological condition that needs to be recognised, it needs to be diagnosed early, and I think that’s probably a really important thing from this ...” (Foot and ankle surgeon)

“... Where awareness is lacking I think is in general practice, whether it be doctors, physiotherapy or podiatry. The awareness is probably not out there. Look at the Map of Medicine; it’s not even in there. At best it’s there as a differential diagnosis for plantar fasciitis [pause]. I’m not concerned when the condition is seen in specialist clinics. It’s what happens to patients outside of there. You need to get in there early to prevent progression ...” (Podiatrist)

Following the analysis thus described, figure 12 highlights the key findings summarised in a data mind map. This illustrates the links made between the themes from the focus group analysis that underwent thematic analysis, the closed question responses that underwent statistical analysis both descriptive and inferential, and the open ended question responses that underwent content analysis.

The following discussion critically explores the triangulated data in a blended approach. This strategy is intended to capture the brevity and depth of meaning from the data, while maintaining a coherent flow. Embedded within the discussion topics in the following pages is the cumulative triangulated data analysis.

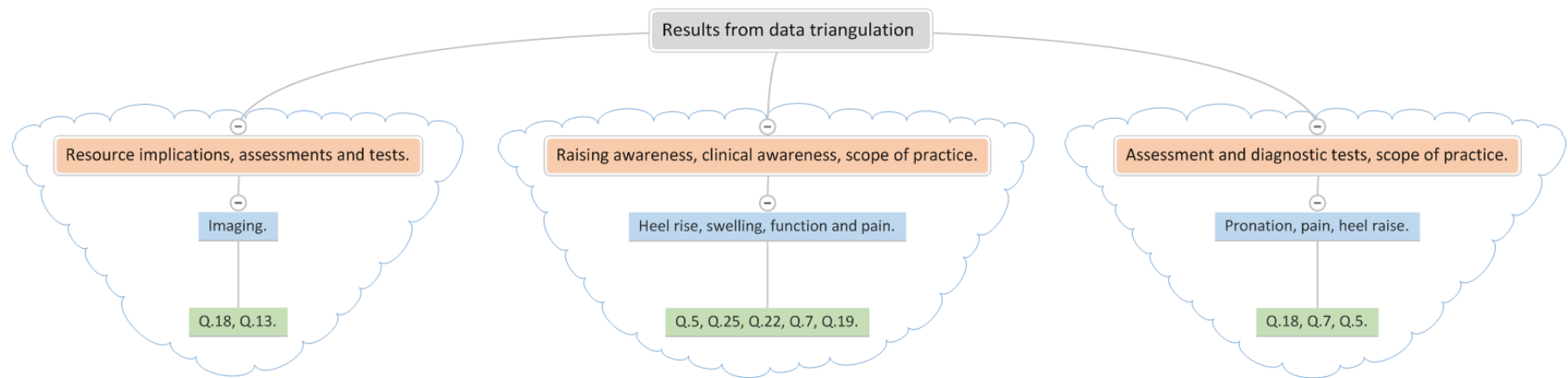


Figure 12: Triangulated mixed methods qualitative and quantitative data analysis

Thematic analysis.

Closed question inferential and descriptive statistical analysis.

4.8 Discussion

Despite its commonality there remains inconsistency surrounding the timely diagnosis and subsequent management of PTTD (Bowring & Chockalingam, 2010; Johnson & Strom, 1989; Kamper et al., 2014; Myerson & Corrigan, 1996; Raikin et al., 2012; Ringleb et al., 2007; Simonsen et al., 2006; Singh et al., 2012). From the small amount of prevalence data available, the evidence suggests that this condition is under-recognised and not well managed within the medical community (Kohls-Gatzoulis et al., 2009b).

Lack of awareness of PTTD was further corroborated by differences in opinion about the predominant age for presentation of the condition; physiotherapists reported between the ages of 20 and 40 years and podiatrists reported between 40 and 60 years. Additionally, opinions on how long it takes to reach a diagnosis from the point of contact with a health professional varied from one week to six months. Statistical analysis supports a lack of agreement both within and between professional groups ($\kappa = 0.874$ ($P < .001$), podiatric medicine $W = 0.041$ ($P = .497$), and physiotherapy $W = 0.060$ ($P = .04$).

Within a group of health care professionals who regularly come into contact with this condition and despite being expert clinicians, interdisciplinary or shared decision making is poor. This is verification of the initial concerns, and a partial motivation for this study.

Fundamental to the success of appropriate intervention is a timely diagnosis. Although general practitioners (GPs) may refer to different professional groups evidence shows that they sometimes do not refer to the most appropriate person to deal with the problem. Clemence and Seamark (2003) explored GP referrals to physiotherapy. The results tended to suggest that the decision making process was variable and not always in the patient's best interest. In some cases the referrals made were referred to as "dumping referrals", where uncertainty existed as to the benefit of the referral. The study revealed that, when patients were interviewed, they sometimes had unrealistic expectations of what physiotherapy would be able to provide. The study concluded that closer working between the two professions would result in the better management of problematic patients and prevent wasted resources by avoiding inappropriate referral.

Despite evidence suggesting that interdisciplinary or multidisciplinary practice provides the best outcomes for patient care (Clemence & Seamark, 2003; Meijer, Sluiter, Heyma, Sadiraj, & Frings-Dresen, 2006), it was apparent from both the questionnaire and the focus group respondents of this study that there remains a narrow focus to the assessment and diagnosis of this condition.

The disagreement about the age group predominantly affected by this condition ($\kappa = 0.054$ ($P = 0.419$), Podiatry $W = 0.297$ ($P < 0.001$) Physiotherapy $W = 0.217$ ($P < 0.001$)) may be reflective of the different patient categories that form the case load of inter-professional groups. This could in turn influence clinicians' perceptions of the onset of the condition. However, it also highlights the uncertainty surrounding correct identification of the condition. Much of the literature cites women over the age of 40 as being the predominant group (Funk et al., 1986; Holmes & Mann, 1992; Johnson, 1983; Kohls-Gatzoulis et al., 2009b; Mann & Thompson, 1985; Pomeroy et al., 1999). Incidence appears to be higher in this group (Kohls-Gatzoulis et al., 2009b), but whether incidence increases with age, and if age related risk factors play a part, remains unclear (Beeson, 2014).

When respondents were asked whether they thought PTTD progressed in a predictable fashion, there was a lack of agreement. Intra professionals and inter professionals were divided about whether the condition was variable or predictable. Fifty percent of podiatry responses thought the condition progressed predictably, 11% that it did not progress in a predictable way, and 41% that progression was variable. For physiotherapy the responses were 30%, 17% and 55% respectively, these results are supported by the statistically significant lack of agreement ($\kappa = 0.527$ ($P < 0.001$), podiatric medicine $W = 0.121$ ($P < .003$), and physiotherapy $W = 0.101$ ($P < .008$)).

This point reveals that, on the basis of the stage of pathology, there is a risk of either missed or incorrect diagnosis. Since all of the current staging criteria clearly indicate that this condition is progressive and at each stage there is a potential for worsening symptoms, a timely diagnosis needs to be provided (Johnson & Strom, 1989; Raikin et al., 2012; Supple et al., 1992; Williams & McClay, 2000). If this is the trend for a specialist

group of MSK professionals, the lack of understanding amongst non-specialist groups could be more prevalent.

This observation is further supported by focus group participants who were in agreement that the condition often suffers from missed or late diagnosis. There was strong opinion that part of the problem in diagnosing the condition is that patients are not seen early enough by clinicians who have the expertise to provide a diagnosis. Overall, the questionnaire survey data suggests that more than 90% of respondents agree that diagnosis of PTTD could be improved. Illustrating this point is a study by Kohls-Gatzoulis et al. (2009) which reports that, of 582 women who were surveyed, with 3% later confirmed to have PTTD, none of them had been previously diagnosed, and this was despite long standing presentation of the symptoms.

One response from the open ended question responses recognises this problem:

"I am often surprised how late in proceedings with any foot pain that a podiatric assessment is considered, which in the case of PTTD is seriously detrimental to the patient's well-being. I find that most PTTD patients have seen at least 3 health professional before seeing me, and often remain undiagnosed until then."

When respondents of the current study were asked whether they thought that the diagnosis of PTTD could be improved, there was positive widespread agreement, with 90% of podiatry respondents and 98% of physiotherapy respondents agreeing that the diagnosis of the condition could be improved. When asked how they thought a patient would benefit from improved diagnosis, 'management' and 'intervention' were two of the most commonly cited words identified during the content analysis of the data. For physiotherapy 23 out of 54 responses and for podiatry 31 out of 48 responses cited one or both of these words.

Exploring how these words were linked with other words and phrases provided a fuller appreciation of the meaning behind them. Linkages included; 'appropriate management', 'better management', 'treatment that slows down deterioration', 'targeted intervention', 'correct treatment and care', 'fast track treatment and care', 'quicker and timely

intervention' and 'targeted intervention' (see mind map appendix 12.3 for full breakdown of responses).

In order to achieve the 'better and appropriate treatments' for patients with PTTD to which respondents allude, the assessment, which ultimately leads to timely diagnosis, needs to facilitate appropriate assessment techniques. Currently there is a lack of detailed information surrounding assessment of this condition, with a paucity of evidence supporting methods of assessment and tests for inclusion.

Questionnaire respondents confirm that both weight bearing and non-weight bearing assessment are essential to the diagnosis of PTTD. For physiotherapy responses 98% considered weight bearing assessment essential and 84% considered non-weight bearing assessment essential. For podiatrists the responses were 98% and 92% respectively.

Chapter 2 outlined some of the issues with the assessment of PTTD and linked them to the use of a variety of protocols and tools available to the practitioner in the form of staging and classification tools. Surprisingly, the debate about assessment of PTTD is not well documented within the literature, but the results from the questionnaire and focus group suggest that clinicians have plenty to say on the topic.

There are a multiplicity of staging and classification criteria within the professional domain to aid understanding of the progression of the disease and highlight the likely signs and symptoms a patient may exhibit throughout progression. However, the intended use of such staging tools is often unclear and combines observation of signs and symptoms with recommendations for treatment and management. In the absence of a clear evidence based assessment guidelines for PTTD, such classification models and tools are often used by clinicians as a basis for assessment, and reference to them for such purposes is now commonplace.

Notwithstanding a positive recognition of the need for a clinical staging tool (80% of podiatry responses and 47% of physiotherapy responses in the core sampling unit question), there were inconsistent responses to what such a tool would include. There was also a mixed response to the open ended questions relating to the context coding topics in this area of discussion.

Further, in response to a question on staging the condition, the majority of the responses referred to assessment and staging rather than staging of the condition per se. This corroborates the suspicion that clinical practice tends to utilise the existing staging criteria to guide assessment of the condition as well as gauge progression.

‘Pain’ was referred to repeatedly both with regard to the impact that pain has on patients and their ability to maintain activities of daily living, and its inclusion within a staging criteria. Podiatry and physiotherapy respondents mentioned the word ‘pain’ in 25 of 45 and 27 of 49 responses respectively. This response also mapped to findings from the weight-bearing and non-weight bearing assessment context coding, and subsequently was identified through the data triangulation. Conversely, none of the current classification or staging/assessment tools recommend a specific pain assessment.

Over half of all participants, when asked what they would include in an assessment/staging tool, positively identified pain assessment as being a necessary component. Responses were far ranging and covered topics such as ‘non-weight bearing pain’ and ‘pain linked to function and activity levels’, pain associated with ‘swelling’ and ‘pain on palpation’. These responses are summarised in Appendix 12.3. When respondents were asked what they considered to be the most common classical patient reported symptoms, 41 of 44 podiatry responses and 41 of 49 physiotherapy responses cited pain as the most common symptom.

Focus group participants also considered pain to be one of the most common symptoms they would look for, in addition to a change in foot shape, when assessing a patient with suspected PTTD.

“... the main point I look for is a change in foot shape in a short space of time, anything of a year or less and a unilateral foot shape, so if they say it’s one foot that’s changing shape ... Ankle pain, that’s medially based to start ...” (Foot and ankle surgeon)

There are pain assessment tools available that would address the majority of the concerns raised by respondents within this analysis.

For example, The Pain and Disability index (PDI) (Tait, Chibnall, & Krause, 1990) is a dynamic pain assessment tool. Construct and discriminant validity demonstrates the

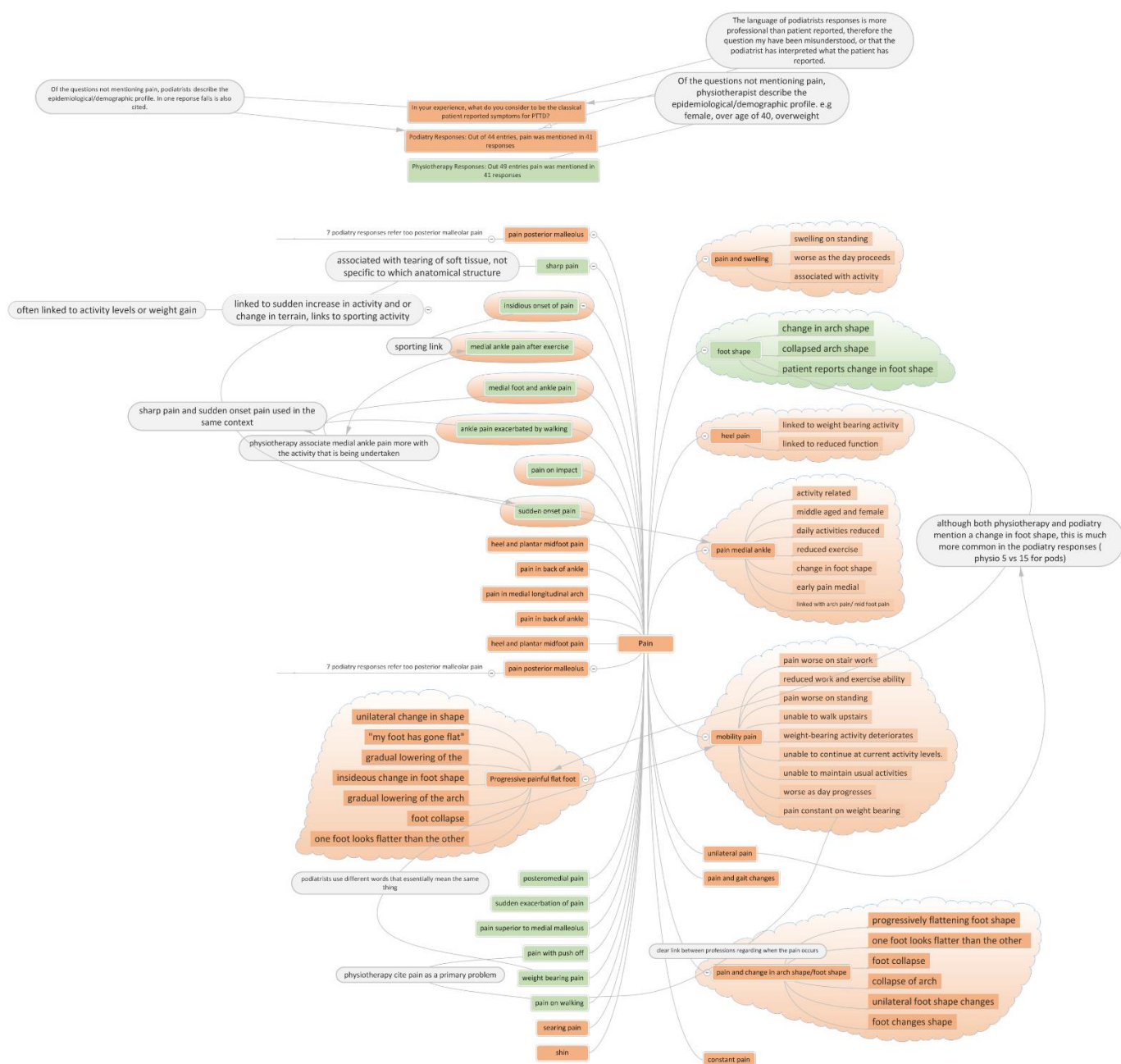
usefulness of this tool in providing functional information that surpasses what could be obtained from using a simple measure of pain intensity such as a visual analogue scale (VAS) (Jerome & Gross, 1991). Until recently this type of pain assessment has not been recommended for PTTD. A recent RCT protocol publication (Blasimann et al., 2015) cites this assessment tool in its proposal to assess the pain associated with non-surgical treatment of the condition. It is considered reliable for the assessment of musculoskeletal pathology and functional impairment in chronic diseases (Gronblad et al., 1993; Jerome & Gross, 1991).

The PDI, or any other pain and disability tool, is not currently recommended in the assessment and diagnosis of PTTD. Despite this, the core question sampling unit regarding pain mapped to two other discrete context coding areas. These were non-weight bearing assessment and classical patient reported symptoms. By far the most complex and comprehensive responses for pain were associated with classical patient reported symptoms. Figure 13 below highlights this. In addition, pain had a strong association with patient mobility and patient independence. In PTTD, this is another under-researched area. The promotion of independence and mobility have been reported as key to developing effective older people's services in the UK (Department of Health, 2006). Research has suggested (Eggermont et al., 2014; Menz et al., 2013) that chronic pain, including foot pain, can have a significant impact on the daily lives of older people, often contributing to a decline in physical performance.

The reference to pain also maps to activity levels and it is one of the key words cited in question 5 discussing classical patient reported symptoms. Activities of daily living such as shopping, stair walking, driving, exercising, walking, ability to go to work were all cited as problematic for patients with PTTD.

A combined pain and disability assessment could help identify these problems at the point of diagnosis, or contribute towards management of the patient once a diagnosis has been made. The mind map below highlights the complexity of pain and its effect on patients' reported well-being, and their ability to mobilise and take part in daily activities. In fact, pain was mapped to most of the other topics discussed.

Figure 13: Mapped from the core sampling unit to the coding unit 'classical patient reported symptoms' highlighting the complexity of responses related to the key word 'pain.'



Other tests identified by respondents to this question, for inclusion into the staging criteria, include foot posture assessment, functional assessment, heel rise test, and ligament assessment. See Appendix 12.3 for mind maps and further information.

Of these responses, 'heel rise' or 'single heel rise' were the most frequently cited words. For podiatry 37% (17 of 45) and for physiotherapy 20% (10 of 49) of responses referred to this word. In other coding units these words were also mapped to: 1) other tests and assessments identified as being important to the diagnosis of PTTD, 2) weight bearing assessment, and 3) classical patient reported symptoms. The latter point related to patients who reported being unable to perform this test. Focus group participants cited inability to perform the single heel rise test at an early presentation. Additionally, focus group participants said that they would include this test in a staging tool.

The single heel rise test was first mentioned in the original staging criteria proposed by Johnson and Strom (1989), however the validity and use of this test is questionable. Chapter 2 have highlighted a number of potential problems with this test, not least the method of execution and the interpretation of the result.

Published work investigating both single and double heel rise kinematic differences (Chimenti et al., 2014; Houck et al., 2009b) and the work presented in chapter 6 indicate that the single heel rise test should be used cautiously in the assessment of PTTD. See Chapter 6 Section 6.8.2, 6.8.7 and 6.9.3 for full discussion related to this.

The core sampling question responses demonstrate a myriad of comments about the single heel rise. These include 'inability to perform the heel rise', 'inversion of the rearfoot on rising', 'functional ability tested by the heel rise test', 'pain on rising', 'pain on rising during multiple heel rises', and 'control of heel rise', to name a few. This suggests that not only might this test be used differently in differing clinical situations, but that the output from the test is also interpreted differently. If there is a lack of agreement about what a test is assessing, how it should be executed and what the results mean, there is surely a case for better evidence for its inclusion in both assessment and staging of the condition.

The next most cited word in the core sampling unit is 'imaging'. Respondents were asked a series of closed questions about imaging. See table 4.7.2 for details on the question and

responses. From the core sampling unit responses, 31% of podiatrists and 8% of physiotherapists cite imaging as something that should be included in a staging or assessment tool.

Results for the imaging questionnaire responses versus the focus group discussions (fig 5-10) provided a surprisingly dichotomous picture. The survey questionnaire results indicated that any type of imaging was not thought to be essential to the diagnosis of PTTD kappa =0.593 ($P=0.001$) Kendal's Podiatry $W=0.091$ ($P<0.01$) and Physiotherapy $W=0.056$ ($P=0.008$). However, focus group discussions suggest that clinical decision making can be enhanced by the use of imaging, particularly soft tissue imaging.

Following discussions on the use of MRI, focus group participants felt that, rather than the lack of access to MRI being a limitation, it has in fact led to an enhanced service provision. Many ESP clinicians are utilising diagnostic ultrasound as a portable cheaper option than compared to MRI. This has enriched their expertise and diagnostic certainty, providing instant clinical information to help confirm a diagnosis and aiding clinical decision making and onward surgical referrals. This was highlighted by one discussion where it was suggested that instant access to diagnostic ultrasound, in addition to enhanced working with orthopaedics and podiatrists and/or physiotherapists in a multidisciplinary (MDT) or interdisciplinary team environment, should be the gold standard that service providers strive to achieve. Content analysis on the context coding responses links MRI to a second line approach to assessing the structure of the tendon, and should be requested if the patient is not responding to intervention.

From the closed question data, it would appear that x-ray is unhelpful in diagnosing the condition for both within and between group analysis kappa=0.757 ($P<0.001$) Kendal's Podiatry $W=0.319$, ($P<0.001$) Physiotherapy $W=0.34$ ($P<0.001$).

The focus group data offers insights surrounding the use of X-ray. Despite this imaging modality not being useful in the immediate diagnosis of this condition, from a surgical perspective, it was deemed to be useful in terms of surgical planning and in assessing the progression of the condition. This suggests that a 'one size fits all approach' is not helpful. Certainly from a diagnostic or conservative therapeutic perspective, X-ray may be less useful. However, in terms of collaborative clinical decision making and the long term interests of the patient, this type of imaging is not redundant.

During the focus group discussions, the foot and ankle surgeon participant suggested that careful assessment with the help of X-ray is useful to determine if the patient is suitable for surgery. This is especially important where a patient's foot demonstrates a progressed presentation of the condition. If a patient has been managing well but has bone and joint degenerative changes as a result of the progressing pathological flatfoot deformity, it may be deemed that long term conservative management is a better option offering a better long term outcome for the patient. Context coding responses from the imaging mind map for podiatry responses associated with question 18 also suggest X-ray is useful in ruling out other bony pathologies such as tarsal coalitions. This suggests that much closer working with different professional groups could also help improve overall management.

An interesting and connected topic integrated with the subject of imaging relates to one of the core sampling unit responses. For some time now there have been suggestions that ligament attenuation is related to PTTD. In particular the calcaneonavicular ligament (CNL), also known as the spring ligament, has been linked to PTTD (Balen & Helms, 2001; Deland, 2012; Jennings & Christensen, 2008; Mengiardi et al., 2005; Menz et al., 2013; Tohno et al., 2012; Williams, Widnall, Evans, & Platt, 2014). This suggests that ligament attenuation may be a more significant factor than originally thought in the progression of PTTD. However, throughout the data collected for this arm of the study, there was a lack of mapping between the core sampling unit, the content analysis context coding and also to the focus group results. This was a surprising finding, given the mounting evidence suggesting the positive association between the two.

Chapter 6 offers significant investigation of this topic in a comparative retrospective study, exploring identification of this anatomically complex ligament using a standard foot and ankle protocol. Please see chapter 6 for further discussion and debate as well as results for the imaging arm of the study.

The final four areas of the core sampling unit demonstrated much smaller word counts (see Section 4.3 above and table 3) than the other areas. Despite the smaller number of respondents referring to the remaining key words, all of these words mapped to the context coding units, and for that reason are deemed worthy of discussion and will be dealt with together in one section.

The words 'foot posture' and 'pronation' will be discussed first. Foot posture was mentioned in the sampling unit by 26% of responses for podiatry and 12% of physiotherapy responses. Some of the other descriptors related to these words include positional changes over time, standing foot posture asymmetry, foot deformity and foot collapse. For pronation, similar words were used including 'foot collapse', 'lowering of the medial arch', and 'hind foot alignment'. For these responses, 'foot posture' mapped to question 19 (consideration of a single overriding factor) with both physiotherapy and podiatry referring to the word twice (2 of 49 and 2 of 39 respectively). The word 'pronation' mapped to question 7 (findings of a weight bearing assessment). Since many of the referrals to this word also linked it to 'rearfoot motion' and 'subtalar joint', this discussion will also include those words. Both rearfoot and subtalar joint mapped to question 22 (findings of a non-weight-bearing assessment).

In the closed questions where respondents were asked if they agreed that a weight bearing assessment was essential to the diagnosis of PTTD, 96% of podiatry responses and 97% of physiotherapy responses replied yes, they thought this was essential. A similar picture was true of a non-weight bearing assessment with 84% of physiotherapy responses and 92% of podiatry responses confirming that yes, they thought this was essential for diagnostic confirmation.

'Excessive pronation, collapsed arch, lack of heel inversion, end stage pronation, prolonged push off, abnormal pronation affecting gait and changes in foot shape' were phrases linked to the word pronation. Related words associated with the subtalar joint produced a plethora of terms such as reduced motion, reduced quality of motion, loss of ankle joint dorsiflexion, loss of active and passive motion, structural changes to subtalar joint, peri articular subluxation, stiffness into abduction, lack of pronation, and deformity. Some of these words also matched other phrases expressed in responses to weight bearing and non-weight bearing assessment. Much overlap is seen with foot collapse, for example, where respondents suggest differential diagnosis, foot a-symmetry and sudden change in foot shape could be seen as an important single overriding factor (question 19). The importance of a differential diagnosis links back to the focus group discussion on imaging, where imaging may be used to rule out other co-morbidities.

Notwithstanding the importance of the terms above, the highest responses for weight bearing assessment were represented by other words and phrases. The three highest scoring words for both physiotherapy and podiatry were, 'navicular', 'medial longitudinal arch' and 'forefoot abduction'. For the word navicular, 17 podiatry responses and 14 physiotherapy responses were recorded, this accounts for 42% and 28% of responses respectively. For medial longitudinal arch, 21 podiatry and 20 physiotherapy, 52% and 40% respectively, and for forefoot abduction 19 podiatry and 16 physiotherapy responses mentioned this word equating to 47.5% and 37% respectively. The term navicular drop is cross referenced both with the term medial longitudinal arch and arch collapse and is mentioned in gait changes, one of the key words in the context coding for question 18.

These responses suggest that there is some agreement regarding key findings of a weight bearing assessment. Forefoot abduction and loss of medial longitudinal arch are observations supported by the descriptors used within the existing staging criteria (Bluman et al., 2007; Johnson & Strom, 1989; Mankey, 2003; Myerson, Solomon, & Shereff, 1989; Raikin et al., 2012; Wainwright et al., 1996).

The terms navicular drop and drift, however, are not terms mentioned in the current criteria, although they have been associated with abnormally pronated feet, and changes in the medial longitudinal arch profile (Brody, 1982; McPoil & Cornwall, 1996; McPoil et al., 2013; McPoil et al., 2009; Menz, 1998; Mueller, Host, & Norton, 1993; Saltzman, Nawoczenski, & Talbot; Snook, 2001; Spornly-Nees et al., 2011; Vicenzino et al., 2000; Vinicombe et al., 2001). Since there is often a close association between medial longitudinal arch, foot kinematics, and a change in arch profile (Cornwall & McPoil, 1999; Dahle, Mueller, Delitto, & Diamond, 1991; Kothari et al., 2014; Vicenzino et al., 2000) it is unsurprising that navicular height, navicular displacement and navicular bulging have been aligned to this perspective.

Despite a multitude of publications investigating the role of the navicular in foot kinematics, arch profile and foot posture, there have never been any reports linking changes to these characteristics and PTTD. Chapter 6 provides the first work of its kind, linking changes in the position of the navicular during kinematic observation in participants with PTTD compared with controls.

The results presented herein suggest there is a need to raise awareness of the condition among non-specialist clinicians. Focus group participants provided a strong sense that little was known about the condition outside of extended scope MSK practitioners. One participant (podiatrist) pointed out that the condition is not mentioned within available diagnostic and assessment tools such as the Map of Medicine; an electronic clinical tool accessed by many non-specialist practitioners for advice regarding clinical pathways and evidence based practice. The questionnaire respondents agreed that the condition could be managed successfully with conservative management. Agreement was also reached confirming that the diagnosis of the condition could be improved (Kappa= 0.62, ($P<0.01$) Kendal's Physiotherapy $W=0.522$ ($P<0.001$), Podiatry $W=0.586$ ($P<0.001$)).

However, as echoed by two respondents, conservative treatment is less likely to be effective if the patient does not receive a timely diagnosis.

"So many times patients end up in a circle of orthotic tinkering while the foot continues to collapse requiring bigger surgery in the end and a compromised result. Try this orthotic for a few weeks and then that orthotic for a few weeks is not good enough but very common in the profession."

"I have found very good success rates in conservative management however feel I see a lot of these patients at stage 3 onward when, finally, a referrer has felt it necessary to do something. I would like to see these patients earlier in progression."

Given that good quality intervention studies are reporting the benefits of conservative management and that, when diagnosed at an early stage, the results appear unequivocal (Neville et al., 2009, 2010; J. Tome, D. Nawoczenski, et al., 2006) it seems crucial that raising the awareness of the condition is one of the most important take home messages.

The published literature, in addition to experiential clinical evidence, suggests a picture of progression of the pathology over time if active management is not commenced (Frowen & Neale, 2010; H. Menz, 1995; Ness et al., 2008; Neville et al., 2007; Nielsen et al., 2011; Picciano, Rowlands, & Worrell, 1993; Pomeroy et al., 1999; Rabbito, Pohl, Humble, & Ferber, 2011).

The focus group data suggest where and when clinics happen, and the model that is adopted in order to maximise access to resources identified variability within different

professional groups and among the same professional group. Some services offer a 'one stop shop' approach to assessment, diagnosis and treatment, and therefore care is provided in a streamlined manner. This would hold true when observing the way newly commissioned MSK services within NHS UK are offering MDT clinics for chronic conditions, with a variety of health care professionals available at one location.

In some community clinics this is sadly not the case and individual clinicians are limited by the assessment equipment and diagnostic procedures, such as imaging, that are available to them. Published reports suggest that patient benefits are plentiful from MDT rehabilitation programs (Sjöström, Alricsson, Asplund, & Nordenmark, 2009). This was echoed in a multiplicity of interactions within the focus group discussions.

Even if the streamlining of referral and the raising of awareness of non-specialist practitioners is achieved there remains confusion at advanced levels of practice as to what diagnostic tests are appropriate. Questionnaire survey respondents, when questioned on their opinion as to whether imaging was essential in the diagnosis of the condition, gave a mixed response. Additionally, when asked which type of imaging they believed was most appropriate in order to confirm clinical findings and diagnostic certainty, responses were inconsistent.

4.9 Summary

The results of this study have demonstrated that within a group of health care professionals who regularly come into contact with this condition and despite being expert clinicians, interdisciplinary or shared decision making is poor.

Lack of awareness of PTTD was further corroborated by differences in opinion about the predominant age for presentation of the condition; physiotherapists reported between the ages of 20 40 years and podiatrists reported between 40 and 60 years.

Additionally, opinions on how long it takes to reach a diagnosis from the point of contact with a health professional varied from one week to six months. The results have clearly shown that the approaches to assessment between physiotherapists and podiatrists are dissimilar and sometimes these two groups of professionals share different aims and objectives surrounding assessment. This has highlighted a lack of agreement surrounding the subsequent timely diagnosis of the condition.

The results of this arm of the study suggest that the reported evidence provides combinations of reasons why PTTD is poorly diagnosed among health care practitioners (Geideman & Johnson, 2000; Holmes & Mann, 1992; Singh et al., 2012). The three main areas for discussion, going forward, are identified as follows:

- i. The need for timely signposting to specialist practitioners to improve the diagnostic profile of this condition.
- ii. The overarching need to raise awareness of non-specialist groups as to the existence of the condition, especially as non-specialist clinicians may be the 'gate keepers' to onward referral to advanced services.
- iii. The need for clarity within advanced services as to the assessment and diagnostic tests that are the most appropriate to aid diagnostic confirmation.

Chapter 7 provides further discussion and synthesis, bringing together the various strands of discursive debate from the points above in addition to the key findings of the discussion in chapters 5 and 6.

Chapter 5: Imaging of the calcaneonavicular ligament (CNL) and its place in the assessment and diagnosis of PTTD

Aspects of this chapter have been submitted for publication

Durrant B., Chockalingam N., Richards P,J., and Morriss-Roberts C. Pragmatic identification of the calcaneonavicular ligament on Routine MRI sequencing in patients: 3T versus 1.5T. *The Foot*, under review.

5.1 Introduction

MR imaging plays an increasingly important role in the diagnosis and differential diagnosis of foot pathologies, including soft tissue lesions of the tendon and ligaments. In the foot this is particularly useful given the large number of tendon insertions, ligaments, bones (Tryfonidis et al., 2008) and joints. Recent advances in 3 tesla (3T) high resolution magnet strength MRI systems offer significant advantages for musculoskeletal imaging. For example, innumerable published studies of the knee report excellent sensitivity and specificity of detecting meniscal tears (Magee & Williams, 2006; Ramnath, Magee, Wasudev, & Murrah, 2006; Sormaala, Ruohola, Mattila, Koskinen, & Pihlajamaki, 2011).

Anatomical studies supporting the role of the calcaneonavicular ligament (CNL) complex, also known as the spring ligament, in the mechanical aetiology of the pathological flat foot condition have grown in the last decade. Its association, in particular, with PTTD has secured an interest in this topic in the clinical field (Deland, 2012; Deland et al., 2005; Herraiz Hidalgo et al., 2014), although until recently experimental evidence was lacking (Herraiz Hidalgo et al., 2014; Tohno et al., 2012; Williams, J. Widnall, P. Evans, & S. Platt, 2013).

Comparative surgical MRI studies of the foot are far fewer than those of larger anatomical areas of the body such as knees and hips, where the anatomical structures are more easily identifiable. Although MRI has been utilised in the foot to characterize anatomical structures on cadaveric specimens, only a few studies have focused on diagnosis in the clinical setting (Trnka, 2004; Williams et al., 2014; Williams et al., 2013; Yeap et al., 2001). Three tesla MRI provides an excellent opportunity for detailed high resolution imaging of the small joints and surrounding soft tissues in the feet, and arguably provides better opportunities for diagnostic observations than 1.5 tesla (1.5T) scanners (Chhabra et al., 2011). Mounting evidence (Jennings & Christensen, 2008; Meagan & Jeffery, 2008; Shibuya, Ramanujam, & Garcia, 2008; Tohno et al., 2012; Tryfonidis et al., 2008; Vadell & Peratta, 2012) that continues to develop our understanding of the suspected contribution that the CN ligament makes to the progression of the pathological flat foot, and in particular PTTD, should not be ignored.

Since this study is seeking to better understand why the diagnostic profile of PTTD is poor and whether there is inter-professional agreement associated with assessment approaches to PTTD, the results presented thus far suggest that further exploration of this topic is warranted.

5.2 Background to the study design

This arm of the project initially intended to image patients with PTTD to investigate the presence of additional ligament attenuation. Assurance from orthopaedic colleagues that damage to this ligament is a frequent finding in patients with PTTD, especially peri-surgically, gave an optimistic projection regarding patient recruitment to this arm of the study. The same group of patients would then be recruited to the kinematic study arm.

However, recruitment from the orthopaedic department was much slower than envisaged. Additionally, the Picture Archiving and Communication system (PACs) staff confirmed that they could not provide the images requested within the required parameters because of the way that the coded data was stored on the database.

Also, the radiologist involved confirmed that she had not received the volume of referrals which the orthopaedic team had led the researcher and her supervisors to expect. Following discussion with the supervisory team it was agreed that this arm of the study would adopt a different focus.

A further review of the literature coinciding with the re-working of the study led to a change in the aim, and subsequently the hypothesis for this arm of the research. The literature on this topic reveals a lack of agreement about what constitutes the CNL and its anatomical function. This has been outlined in the introduction of this chapter. Further, it is unclear from the literature, why some studies do not report on all three bands of the ligament.

With the advent of ever more powerful magnets an opportunity presented itself to investigate the impact this has had on both the positive aspects of improved resolution, and the opportunity to explore whether better resolution enables more complex structures, like the three bands of the CNL, to be studied. Additionally, studies published identifying the three bands of the ligament have been conducted on anatomical specimens, and therefore not subject to some of the restraints of a busy NHS imaging department, where a standard foot and ankle protocol is in place.

5.3 Anatomy of the CNL

The term 'spring' ligament is associated with the CNL complex as its function is compared to the action of a spring in supporting the medial longitudinal arch (Agur, Lee, & Grant, 1999). This function has since been widely debated, and while many disagree with the notion of a spring function, the name has remained (Mengiardi et al., 2005).

The CNL is a large, complex ligament with three components which run from between the middle and anterior calcaneal facets to the navicular tuberosity. The superomedial component runs along the anterior border of the middle facet of the calcaneus. The superficial fibres of the ligament merge with the tendon sheath of the tibialis posterior and the deeper fibres insert onto the medial articular facet of the navicular. The inferior component runs along the notch between the anterior and middle facets of the calcaneum and inserts onto the navicular beak (Mengiardi et al., 2005). The inferior portion of the CNL is least reported upon and therefore little is known as to its importance in the overall structure and integrity of the ligament. The anatomical variance of this ligament is also unknown (Taniguchi et al., 2003).

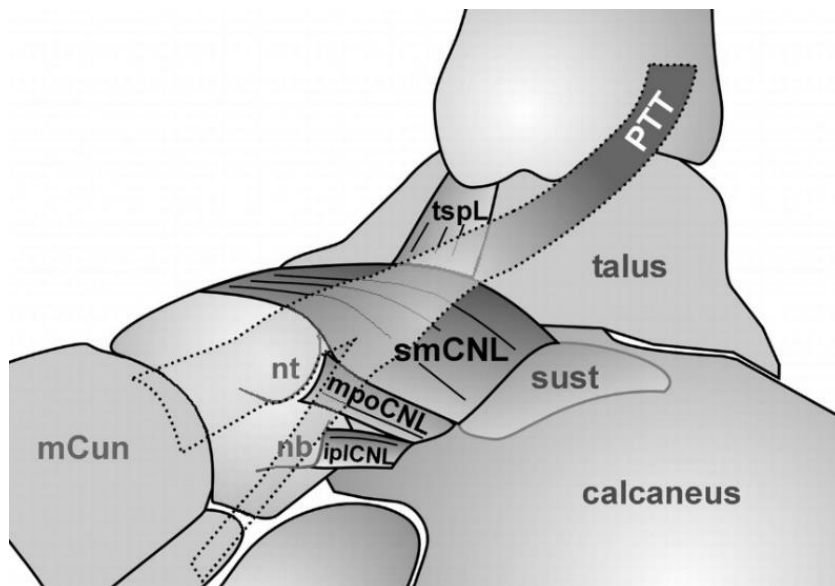


Figure 14: Components of the spring ligament².

² Reproduced with permission.

Mengiardi B, Zanetti M, Schöttle PB, et al. Spring ligament complex: MR imaging— anatomic correlation and findings in asymptomatic subjects. *Radiology* 2005;237:242- 249.

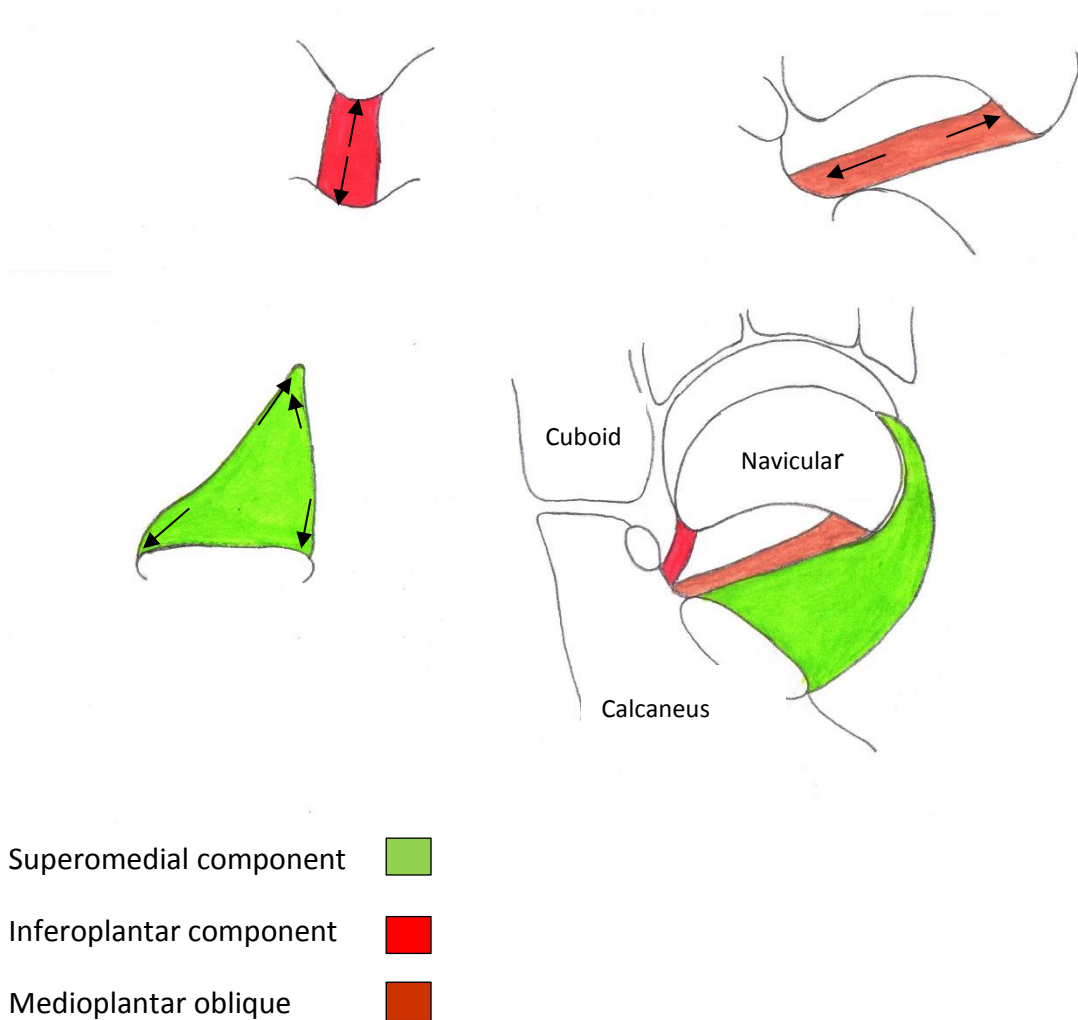


Figure 14 (a): Components of the spring ligament indicating direction of applied forces on weight bearing.

The function of the spring ligament has been debated with relation to its name. Once thought to be one of the key findings associated with the imaging characteristics of this ligament is provided by a study that examined both cadaveric specimens and a volunteer healthy population (Mengiardi et al., 2005). Three distinct components of the ligament were noted as described above. The study confirmed that in a healthy population it is possible to distinguish the three components of the spring ligament complex, albeit it that the medioplantar oblique portion was seen less consistently (77%) than the superomedial or the inferoplantar. The researchers also noted an intermediate signal seen in T2 weighted images on the superomedial component and the striated appearance of the medioplantar oblique on T1 and T2 weighted images (Mengiardi et al., 2005). This further complicates this clinical imaging conundrum. If some components of the ligament appear to be pathological in an a-symptomatic population and are inconsistently seen

(medioplantar oblique seen in 77% of a-symptomatic participants), how does the interpretation transfer to a pathological population? With the advent of more powerful magnets the variable identification may improve, thereby reducing this uncertainty.

5.4 MRI imaging of the foot

The CNL functions as a sling to support the head of the talus. The ligament is a curved structure, which provides a challenging surface to image. Comparative studies between magnet sizes are few for identification of tendons and ligaments in the foot, however work has been done exploring these structures in the hand (Wieners et al., 2007). To date the authors are unaware of any published studies that have compared 1.5 and 3 tesla MRI for clinical comparison to identify the small ligamentous structures in the foot on routine sequences.

Sormaala et al. (2011) published the results from a small cross sectional study examining the relationship between magnet size and the efficacy of the identification of stress fractures in the foot. All participants had previously been positively identified with small bone stress fractures on plain x-ray. Results were interpreted independently by two different radiologists. The study concluded that 3T images afforded better resolution to detect bone marrow oedema. The results were inconclusive for direct comparison of identification of acute stress fractures and the authors therefore concluded that these stress injuries can be made with 1.5 field strength, because the oedema is so conspicuous. Nonetheless, the authors concede that 3T images may better contribute to the diagnosis of other conditions such as infection and malignancy, and recommended future research comparing magnet strength for a variety of pathologies. Further justification comes from the plethora of clinical studies linking CNL attenuation with pathological flat foot pathologies, in particular PTTD (Deland, 2012; Deland et al., 2005; Dunn et al., 2004; Gazdag & Cracchiolo, 1997; Gluck, Heckman, & Parekh, 2010; Herraiz Hidalgo et al., 2014; Hintermann, 1997; Kettelkamp & Alexander, 1969; Kohls-Gatzoulis, Angel, et al., 2004b; Mengiardi et al., 2005; Mosier et al., 1999; Muhle, Brinkmann, Brossmann, Wesner, & Heller, 1997; Nielsen et al., 2011; Tryfonidis et al., 2008; Yeap et al., 2001).

One explanation for the low reporting of the identification of CNL pathology is the poor clarity of anatomical structures due to the lower resolution afforded by the 1.5T MRI

compared to the 3T scanners. Since 3T scanners are becoming more commonplace it is timely to investigate this. Although other factors such as clinical experience, specialist capacity of radiologists and protocol adopted etc. may play a role in the paucity of reporting, magnet size appears to be another plausible explanation.

This study hypothesised that magnet size makes no difference to identification of the CNL components. Secondly, it hypothesised that standard MRI foot and ankle protocols do not provide sufficient certainty that identification of the CNL will be sufficiently high in a pathological population.

5.5 Aims

This re-worked arm of the study has two primary aims:

1. To identify the frequency of identification of the three bands of the CNL using a standard foot and ankle protocol.
2. To determine the conspicuity of each part of the spring ligament on conventional, previously imaged foot and ankle MRI sequences, on a 1.5 or a 3 tesla magnet.

In conducting this study two of the three principal research questions (see Section 2.4) will be partially addressed:

1. Is there a disconnect between interdisciplinary opinions and beliefs surrounding the assessment and timely diagnosis of PTTD?
2. What contribution does interdisciplinary consultation make to the exploration of assessment approaches for PTTD with a view to clinical protocol development?

5.6 Methods

5.6.1 Sampling

The appropriate approvals were sought and given prior to the study being conducted (see appendix 12.8). From March 2011 to December 2012 a sample of foot and ankle cases was requested from the PAC's department within an NHS Hospital Trust (N=197).

5.6.2 Inclusion/exclusion criteria

The criteria used to search the PACS database were as follows:

Standard ankle protocol, MRI images only, no contrast, ankle/and /or ankle and rear foot images only, adults over the age of eighteen. The sample was non-specific to PTTD or known CNL ligament attenuation. Of the 198 patients identified using these search criteria, 101 were excluded. The reasons for exclusion included: contrast used, child, incomplete sequences, movement artefact, non-standard sequences, and severe swelling. This left a sample size of 97 MR images for inclusion in this study.

5.6.3 Procedure

The images were subdivided into two cohorts: those sequences performed using a 1.5T (group 1, N=41) and those using a 3T scanner (group 2, N=57). All scans were conducted following a standard foot and ankle protocol that had been adopted by the hospital trust, on either a 1.5 tesla (Intera Phillips scanner, Netherlands) or a 3 tesla (Skyra Siemens scanner, Germany). Patients were not scanned on both scanners. The standardized protocol provided sagittal T1, and STIR, coronal PD FS, axial T1 and T2 weighted spin echo sequences, without contrast.

Each of the sequences were randomly evaluated independently and then cross referenced against the series. All scans were reviewed by one of the senior radiologists (PJR) who had 17 years' experience as a musculoskeletal radiologist. The written notation was switched off on the monitor, to blind the assessor to the name, demographics, scanner type, and magnet size (1.5 or 3). The results were recorded and logged by the primary author (BD). Results were recorded for each sequence for the three different components of the CNL. The slice thickness had been standardised according to the protocol to 3mm for both scanners for the study period. The method for identification was similar to that reported in 2013 (Williams et al., 2013). Both authors involved in the evaluation of the data were blinded to the diagnosis given by the radiologist at the time of the initial scan.

5.7 Data analysis

Once the data was collected the focus was on three main areas of analysis. First it was established whether the gross anatomy of the ligament could be seen, then, secondly, which individual anatomical components of the ligament could be identified (described as the medioplantar oblique band, the inferoplantar and the superomedial bands (Mengiardi et al., 2005), and thirdly whether pathological or not. For the analysis the authors

extracted the individual MRI sequences for sagittal T1 & STIR, axial T1 & 2 and coronal PD. This provided analysis for eight variables in total. The overall results for each are displayed in figure 12. Table 4 displays the frequency distribution in figures and percentages for all the variable studies for the two magnet strengths. The cohorts of data from each MRI scan were compared. Table 5 summarises the statistical analysis.

5.8 Results

Table 4: Frequency of CNL findings on 1.5T and 3T MRI sequences.

Participant demographics: Female to male 49/71, mean age (range) 46 (24-84)

	Frequency with which each component of the CNL was identified for 1.5 n=41 and 3T n=57											
	Sagittal T1 1.5T	Sagittal T1 3T	Sagittal STIR 1.5T	Sagittal STIR 3T	Axial T1 1.5T	Axial T1 3T	Axial T2 1.5T	Axial T2 3T	Coronal PD FS T1.5	Coronal PD FS 3T	Total 1.5T	Total 3T
Superomedial	4 (9.7%)	1 (1.9%)	3 (7.3%)	1 (1.9%)	7 (*=2) (17.7%)	19 (*=2) (33.3%)	6 (*=1) (10.5%)	15 (34.1%) (*=3)	35 (*=5) (85.3%)	44 (*=3) (77.1%)	66	69
Inferoplantar	10 (24.3%)	11 (19.2%)	8 (19.5%)	17 (*=3) (29.8%)	17 (41%)(*=2)	18 (*=3) (31.5%)	17 (41%)	19 (*=3) (33.3%)	2 (4.8%)	2 (*=1) (3.5%)	60	70
Medioplantar oblique	14 (34.1%)	12 (*=1) (21%)	5 (12.1%)	11 (*=2) (19.2%)	13 (*=4) (31.7%)	24 (*=4) (42%)	17 (*=4) (41.4%)	25 (*=6) (43.8%)	24 (*=4) (58.5%)	32 (*=4) (56.1%)	73	90.5
Total	28	24	16	29	37	61	40	59	61	78		

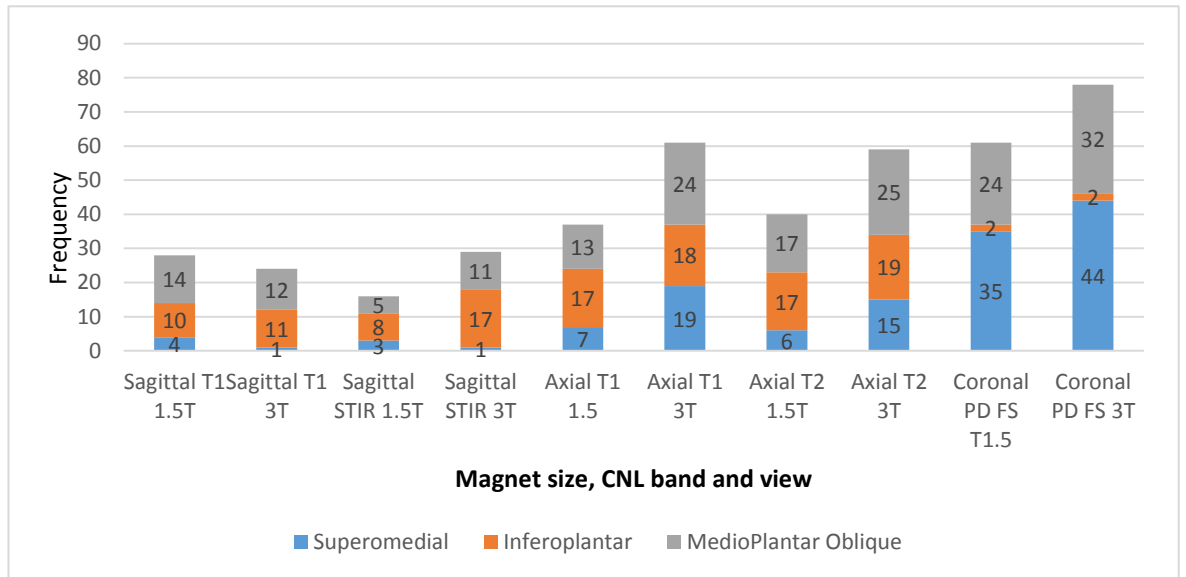


Figure 15: Overall frequency distribution for each view, magnet and CNL band.

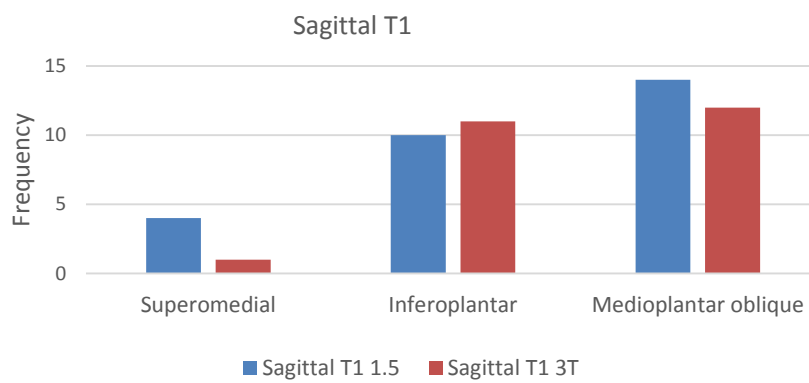


Figure 16: Sagittal T1 for the three CNL bands.

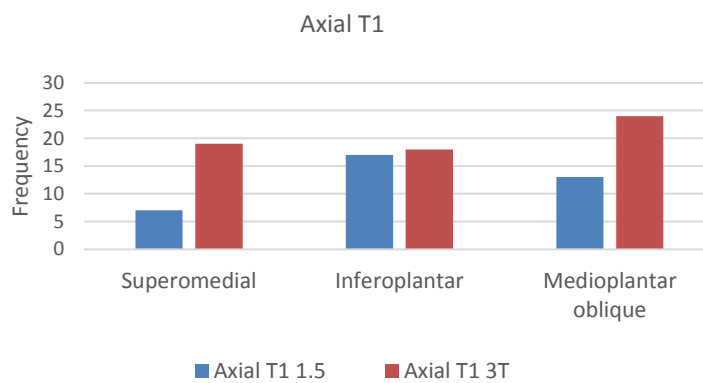


Figure 17: Frequency identification of axial T1 and axial T2 for the 3 CNL bands.

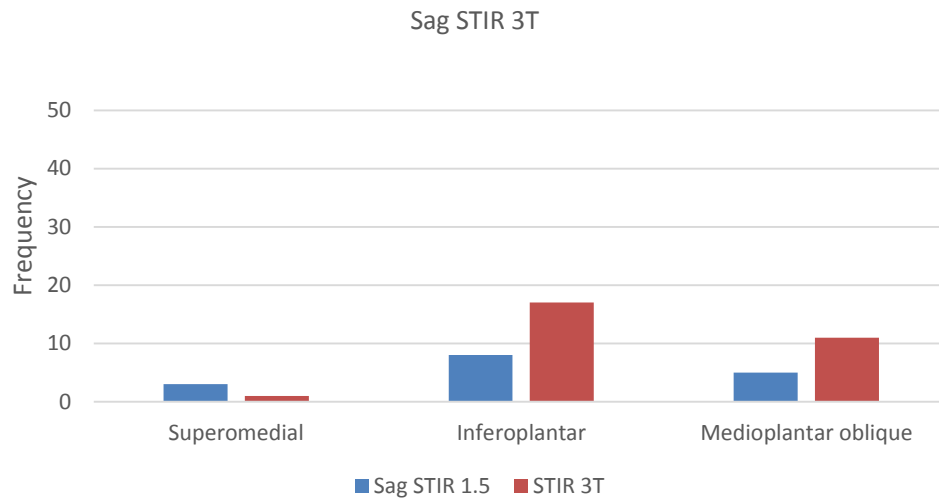
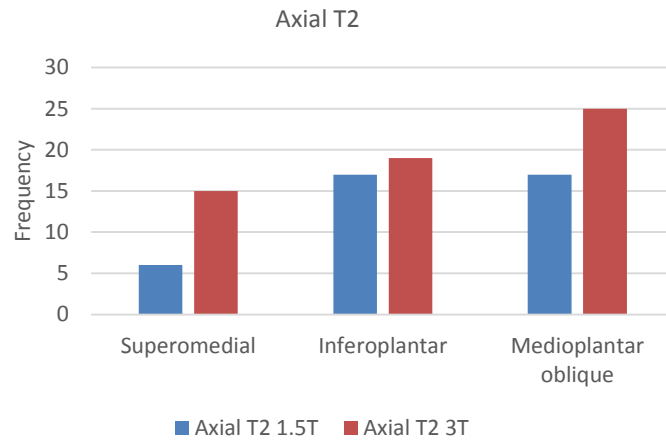


Figure 18: Frequency of identification of Sagittal STIR for the 3 CNL bands.

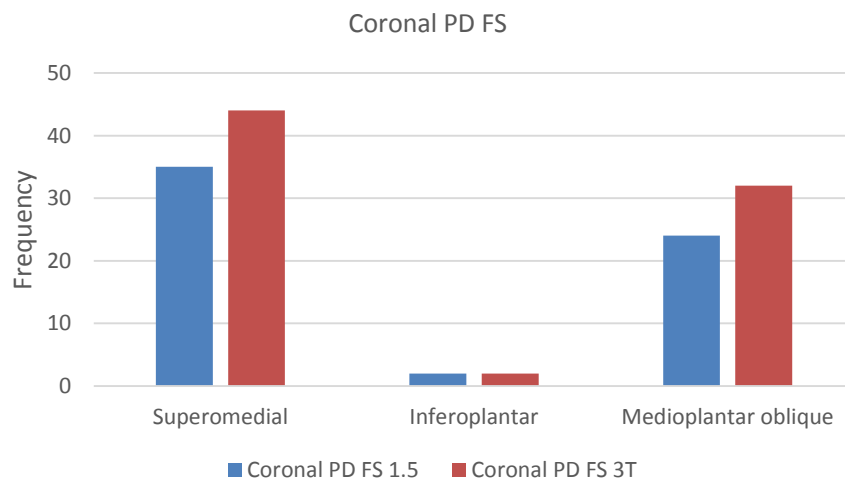


Figure 19: Frequency for coronal PD FS for the 3 CNL bands.

The results for the frequency of detection of the CNL for each of the sequences are reported in table 4. All figures indicate $P < 0.05$ except for axial T1 where $\chi^2 = 3.325$ (1) ($P = 0.05$) indicating that magnet size significantly affects the frequency of identification of the superomedial component of the CNL on the axial T1 sequences. See table 4 for further information.

Percentage frequencies were varied for each of the sequences. For the superomedial band sagittal T1 = 9.7%, STIR = 7.3%, axial T1 = 7.7%, axial T2 = 10.5%, coronal PD = 85.3%. For the inferoplantar band sagittal T1 = 24.3%, STIR = 19.5%, axial T1 = 41%, axial T2 = 41%, coronal PD = 4.8%. For the medioplantar oblique; sagittal T1 = 34.1%, STIR = 12.1%, axial T1 = 31.7%, axial T2 = 41.4%, and coronal PD = 58.5%. For the 3T the superomedial band, sagittal T1 = 1.9%, sagittal STIR = 1.9%, axial T1 = 33.3%, axial T2 = 34.1%, coronal PD = 77.1%; inferoplantar sagittal T1 = 21%, sagittal T2 = 19.2%, axial T1 = 31.5%, axial T2 = 33.3%, coronal PD = 3.5%; and for the medioplantar oblique the sagittal T1 = 21%, sagittal STIR = 19.2%, axial T1 = 42%, axial T2 = 43.8% and coronal PD = 56.1%.

5.9 Statistical analysis

Chi square analysis was performed to establish whether identification of the three components of the CNL was independent of magnet size. Our hypothesis therefore was that magnet size had no effect on the identification of the three components of the CNL. Significance was set at 0.05, expected frequencies >5 for each variable and standard residuals <+/-1.96. Table 5 summarises these results.

Table 5: Summary of statistical analysis.

	Results for Chi Square analysis for each sequence and each ligament band (= df)				
	Sagittal T1	Sagittal STIR	Axial T1	Axial T2	Coronal PD FS
Superomedial	3.154(1) <i>P</i> =0.096	1.885(1) <i>P</i> =0.196	3.235(1) <i>P</i> =0.057	1.933(1) <i>P</i> =0.126	0.019(1) <i>P</i> =0.228
Inferoplantar	0.367(1) <i>P</i> =0.358	1.335(1) <i>P</i> =0.179	1.015(1) <i>P</i> =0.213	0.678(1) <i>P</i> =0.270	0.114(1) <i>P</i> =0.559
Medioplantar Oblique	2.098(1) <i>p</i> =0.112	0.881(1) <i>P</i> =0.257	1.097(1) <i>P</i> =0.202	0.056(1) <i>P</i> =0.489	0.056(1) <i>P</i> =0.489

5.10 Discussion

The results of this study demonstrate considerable variability with regard to identification of the component bands of the CNL and magnet size. The overall results for magnet size for both the sequences and for identification of the CNL indicate that detection of the anatomy as described is not dependent on magnet size. Further, the descriptive findings demonstrate an inadequacy and uncertainty from a diagnostic point of view of the normal presence of pathology. The frequencies reported for each of the ligament bands

for each of the sequences described range from 4.8% to 85.3% for the 1.5T magnet and 1.9% to 77% for the 3T.

Comparing the results of the data collected and presented for this study with the literature is challenging due to the variability in reporting of the ligament's anatomical construction. Often the CNL is reported as being a two banded ligament. (Mengiardi et al., 2005); Taniguchi et al. (2003); Tokuda, Awaya, Taguchi, and Matsunga (2006) have all identified the presence of a "third ligament" within the CNL complex. The authors (Mengiardi et al., 2005), consistently found the third portion of the ligament, in both the cadaver dissections (n=5) and the MRI for both the a-symptomatic subjects (n=78). However, the results of this study refer to an a-symptomatic 'normal' population. The study acknowledges that there is inconsistency in identification and signal intensity on T1 and T2 weighted images for the medioplantar portion of the ligament. In addition, the authors note that for the medioplantar band, in a normal population, identification only reached 77%.

The results for this arm of the study have shown much smaller numbers for positive identification of the medioplantar ligament in a patient population. On axial T1 for the T1.5 the percentage identification only reached 31.5% and for 3T 42%. Similarly, for the coronal PD FS the figures for T1.5 are 58.5% and T3 56.11%. Although the results presented here have not undergone analysis for sensitivity and specificity, they suggest that detection and therefore sensitivity decreases in a pathological cohort of participants.

Furthermore, results published by Williams et al. (2014) confirm that the medioplantar ligament was only reported in PT tendon pathology in 75% of cases. Despite this data, however, the interpretation of this finding remains unclear given that similar figures have been reported for an asymptomatic population. Results provided from this study demonstrate a lower percentage frequency of identification for all data when compared to other published studies, suggesting that caution must be exercised in terms of the inferences drawn from such data.

The results from the current study appear to conflict with other reported figures that have utilised a 1.5 tesla scanner to identify the CNL. There is an inherent difficulty in imaging this field, as with progressive flattening of the foot, the orientation of all ligaments changes, apparently unpredictably. The results reported here are in contrast to those reported by other studies. Williams et al. (2014) report much higher positive identification values; 93-95% for the superomedial band and 84.6% for the medioplantar oblique band (the inferoplantar band was not reported on, and it is therefore possible that the authors merged data sets). Instead of reporting images from their own findings, the authors of this study (G. Williams, J. Widnall, P. Evans, & S. Platt, 2013) interestingly reproduced a diagram used by another author (Mengiardi et al., 2005). However, the diagram had been modified to remove the inferoplantar band, presumably to justify not reporting this aspect of the ligament. This possibly suggests that either there is significant variability in the presence of this portion of the ligament or that there are differences in anatomical appearance on 1.5T MRIs compared to 3T. Alternatively, it is seen in some slice orientations and not others, which would concur with the results reported here.

Other factors affecting the results could be related to the experience of the machine operator, the experience of the radiologist and the nature of that experience. However, the reporting radiologist for the study results presented here has a similar profile in terms of experience to the radiologists in other published studies. The radiologist providing the interpretation of the MR images was a musculoskeletal radiologist and therefore familiar with the anatomy in question. Similarly, poor reliability/repeatability was minimized in our study by having the same radiologist report on all the sequences for all images selected for the study.

The former study (Williams et al., 2013) reported descriptive statistics and compared a small (n=13) group with known CNL tears. CNL pathology was identified at the time of surgery, and the authors do not indicate whether the MR image that was retrospectively reviewed for the study actually identified CNL pathology at the time of the MRI or even if this was a consideration prior to surgery. Therefore, it could be argued that while this study (Williams et al., 2013) does add to the body of knowledge surrounding the MRI

features of CNL attenuation, it does not add to our understanding of prospective identification and how the paucity of prospective identification may affect the contribution this ligament makes to PTTD.

Notwithstanding this point there is a high association between radiology findings confirming the presence of 'arch collapse' and MRI findings confirming the presence of CNL attenuation (Williams et al., 2014). Given that this was a retrospective study, there was limited clinical information regarding symptoms on the referral, nor was there always a clinical examination of the patients involved. The authors have therefore not accounted for those in the population who may have an asymptomatic pes planus foot type. The authors do concede however that the population studied had almost double the number of radiographic flat feet compared with figures reported for a large epidemiological study (Tryfonidis et al., 2008). Despite this, the results of this study are highly statistically significant.

The link between the pathological flat foot and the CNL may have been understated, possibly due to the difficulty of obtaining diagnostic quality in imaging, and because the complex orientation of the ligament precluded adequate imaging in a single plane. The current study has attempted to compare not only magnet size but both planar sequences and individual components of the ligament. The variances in how MRI findings are reported makes comparative analysis challenging; for example, Williams et al. (2014); Williams et al. (2013) have not reported findings for individual sequences, nor have the three components of the ligament been reported.

The association of the CNL with pathological flat foot deformity is widely debated and although there appears to be clinical evidence to corroborate this link (Deland, 2012; Herraiz Hidalgo et al., 2014; Hintermann, 1997; Mengiardi et al., 2005; Yeap et al., 2001), there remains uncertainty about CNL attenuation occurring in isolation and whether this may have a tendency to precipitate PTTD (Gazdag & Cracchiolo, 1997). Before the link with CNL attenuation and PTTD can be established there must be some consistency in the

reporting of both the anatomical structure and also the imaging protocol adopted, as well as increased diagnostic certainty based on MRI findings.

The published evidence would suggest the CNL has become more prominent in the minds of clinicians treating pathological flat foot disorder (Balén & Helms, 2001; J. T. Deland, 2012; Harish et al., 2007; Jennings & Christensen, 2008; Meagan & Jeffery, 2008; Tryfonidis et al., 2008), in fact, some reports suggest it has become commonplace to associate CNL attenuation with conditions such as PTTD. However, the result from the data presented in chapter 5 challenges this supposition.

The inductive approach to the qualitative data analysis, and the deductive approach embraced for the quantitative closed question responses, identified discord between inter-professional approaches to the assessment and diagnosis of PTTD. One of the epistemological benefits of the mixed methods methodology is that it allows for a triangulated approach to the data analysis. This multifaceted approach provides a depth and breadth of analysis which arguably is lost when following a single ontological and epistemological stance. This was evident in chapter 4, and extends to the results presented here; it highlights disagreement surrounding the topics of imaging and ligament involvement in the assessment and diagnosis of PTTD.

When mapping the open ended questionnaire responses to the core sampling data analysis, the context coding only reported 5 of 45 (11%) of podiatry respondents referring to the word “ligament”. There were no such references from the physiotherapy responses.

Although the content analysis and the core sampling coding of the questionnaire responses associated the word “ligament” with the assessment and diagnosis of PTTD, it is difficult to appreciate, from the mapped responses, precisely which anatomical structure was being referred to (see mind map for question 27 in Appendix 12.3). Linked words and phrases included pathology of surrounding soft tissue such as ligaments, ligament attenuation, ligament rupture, and ligamentous augmentation. None of these responses provide enough anatomical detail to identify the ligament or soft tissue in

question. This suggests that not only is there a lack of awareness of the involvement of the CNL in the development of PTTD, but also a lack of appreciation of the anatomical structure and its contribution in supporting the medial longitudinal arch.

Discursive debate about the use of imaging in the assessment and diagnosis of PTTD reveals both intra and inter professional disagreement surrounding the necessity and the most appropriate type of imaging for assessment and diagnostic purposes. Figures 9 and 10 in section 5.7.3 illustrate this. Moreover, focus group participants highlighted that inter professional opinion on imaging is diverse, demonstrating a dearth of opinion on the topic. The quotes below from the focus group meeting highlight this point.

“... You see I would say the thing with that is ... if you’re considering surgery, getting an MR is ... you know, is obviously necessary, so you get it, but if you’re ... if in your practice you’re not, then I would... why are you actually doing the MR scan because you know.” (Physiotherapist)

“I think 70% of people will do an MRI ... real time ultrasound facility which is probably gold standard just in terms of management, but I think probably 70% of people will MR and 30% will ultrasound.” (Foot and ankle surgeon)

“Well I don’t think we do it a lot, I’ll be honest, but I think ... it’s there now ... we’ve only just had the ability for MRI but I think if it’s a grade where there’s a tear I tend to ... tend to sort of suggest MRIs to give an opinion as well ...” (Podiatrist)

“... I mean I think as a gold standard of treatment I think that’s probably going to be it, where you’ve got a surgeon and a podiatrist sitting together and you say I think this is tib post, you ultrasound it ... any time you’re unsure you then say actually I’m going to go on and MR this, or I’m not sure about the subtalar joint, I’m going to have a look at the MRI.” (Foot and ankle surgeon)

The lack of consistency regarding imaging preferences in the assessment and diagnosis of PTTD is thought, in part, to be related to the disparate evidence for the use of ultrasound and MRI, especially for observations of small anatomical structures in the foot. Also important, as emphasised by the focus group discussion, is the purpose of the imaging

request. Certainly, focus group participants were clear that the differing remits that health professionals have in caring for the patient can lead to differing opinions when making assessment and diagnostic choices and this included imaging choices. Section 4.7.5 explained this point.

Given that many of the published research findings pertaining to CNL identification utilising MR imaging were based either upon non-pathological 'normal participants' in an experimental setting, or on cadaveric limbs which had been dissected and then imaged, a conundrum exists as to how relevant this is to daily practice. This, in addition to the observation that many published papers report on the ligament as a peri surgical finding, rather than a prospective surgically planned observation, suggests that there is an element of coincidence in the identification of ligament pathology. Indeed, of the published works available furthering our understanding of this complex problem, many are surgically focused (Deland, 2012; Deland et al., 2005; Muhle et al., 1997; G. Williams et al., 2013).

The higher resolution offered by 3T MRI may offer a better chance of prospective identification. However, other issues, such as positioning of the foot may also have an impact on optimal identification. Kinematic MRI has been used in previous studies to identify positioning variances for larger structures such as patellofemoral, shoulder and ankle joints. Kinematic MR imaging involves evaluation of the various interactions of the important soft tissue and bony anatomic features that comprise a joint, and the relative alignment of these structures through a specific range of motion. (Sans et al., 1996; Tokuda et al., 2006). One study has also used this technique for the foot and ankle ligaments, including the CNL. The authors (Harish et al., 2007) report that the poor identification of the ligaments and tendons in the ankle and foot is most likely explained by an inadequate appreciation of the three-dimensional orientation of each ligament. Failure of standard imaging protocols, such as the one used for our study, to adopt variances in position to reach optimal anatomical identification, could be contributing to the discord in reported findings. To standardize, a link between the degree of medial plantar arch collapse and ligament orientation is required. This is unlikely with current

MRI practice. Previous reports suggest that adopting a neutral foot position for MRIs of the foot and ankle should be avoided (Harish et al., 2007).

An alternative method of assessment of these structure could utilise a relatively new technique called magnetic resonance elastography (MRE). The MRE obtains information about the stiffness of tissue by assessing the propagation of mechanical waves through the tissue with a special magnetic resonance imaging (MRI) technique (Mariappan, Glaser, & Ehman, 2010). At this time there is little research using this technique in assessing foot structures.

Renewed interest concerning the anatomical composition of the ligament has furthered the debate surrounding the role this ligament may play in the development of pathological flatfoot and more specifically PTTD. The new information presented here has added to the debate about the significance of the CNL both in the presence of disease and in its anatomical make up and therefore its function.

Given that there is uncertainty in a number of areas concerning the CNL, including its anatomical make up, the role it plays in the development of the pathological flat foot and more specifically PTTD, the best method for imaging the CNL, and the involvement each individual component has in PTTD, it is questionable whether the advice to clinicians is clear in terms of the most apposite method for imaging the CNL.

The study reported on in this chapter questions whether MRI, irrespective of magnet size, is the most appropriate imaging modality. The frequency of identification is low for this study, and the results are juxtaposed with some previously published values. Previous research (Harish et al., 2007; Harish, Kumbhare, O'Neill, & Popowich, 2008) has indicated that diagnostic ultrasound is as effective as MRI in detecting the superomedial component of the CNL. Harish et al. (2008) reported a 94% concordance for identification of the superomedial component when compared with MR imaging in a small pathological sample of 18 patients. In baseline data the same authors determined a 100% identification rate in asymptomatic volunteers (Harish et al., 2007). However, if it can only evaluate one third of the CNL this is of limited value. Results from this study suggest

that, given the variability in MRI reporting, until there is greater certainty, diagnostic ultrasound remains a cheaper and probably more accessible option for CNL imaging, albeit that the evidence is limited identification of the superomedial component only.

Anatomically, the posterior tibial tendon is radiographically less challenging to image than a deeper, multiplane structure like the CNL. The PT tendon is superficial to the CNL, and therefore imaging the CNL brings depth and resolution challenges for ultrasound imaging. In clinical (non-surgical) practice, diagnostic ultrasound is often employed to help make a timely and cost effective contribution to the diagnosis of pathological flat foot and PTTD. Some studies have confirmed that ultrasonography is useful in detecting the pathological superomedial band. However, there is little evidence supporting the identification of both the inferopltar and the mediopltar oblique components (Harish et al., 2008). This is somewhat limiting in clinical practice since evidence confirms that the ligament is comprised of more than the superomedial component.

5.11 Limitations of the study

The limitations of this study are multifarious. The retrospective nature of the investigation meant that the cohort selection was made via the imaging database; this may have led to selection bias and therefore may have affected the validity of the sample. Limited clinical data was available and was restricted to that which had been previously reported and uploaded to the database. For the identification of the CNL components, a non-standardised identification method was adopted which did not include factors such as quantification of ligament attenuation; for example, the thickness of the ligament components and the TP tendon were not obtained. The fact that this study compared two cohorts of patients on two separate scanners and that we did not scan one patient on both scanners or have surgical confirmation of the MRI findings is probably the main limitation, and if repeated the authors would recommend a prospective design with patients being scanned on both 1.5 and 3T scanners.

Finally, this study utilised images that had already been requested for foot and ankle problems other than PTTD or CNL attenuation. This could have had an adverse effect on

case type. Although standard foot and ankle protocol was employed by the trust it is unknown if this may have been modified within acceptable parameters for prospective referrals, specifically requests TP tendon or CNL imaging, in order to gain optimal identification success.

5.12 Summary

Clinicians frequently cite the CNL ligament as a differential diagnosis for PTTD and orthopaedic surgeons routinely carry out surgical repairs to this ligament at the time of surgery for PTTD, thus it seems sensible to establish whether standard foot and ankle MRI protocols are able to positively identify this ligament. The advancement of MR imaging could make this possible, although the results presented here have indicated both significant variability in the reporting of findings, and difficulties in comparative reporting across clinical areas. It appears that imaging for the CNL remains sub-standard.

Although this arm of the study has not achieved what was intended at the outset, it has offered an original contribution to the detection of the CNL ligament on MRI. The main impact of these findings relate to the definition of 'a normal signal', indicating no pathology. The images used for this study were for patients who had not been diagnosed with PTTD or any such pathology related to the plantar region of the foot and yet in some cases the observations made on MR imaging where a mixed signal was observed suggests there may be pathology present. In an indirect way it has also provided a framework, going forward, for further investigation and a closer alignment with the assessment and diagnosis of PTTD. While it has been acknowledged that there were some shortcomings with the study methods and protocol, the results discussed in this chapter have not been explored before in this manner. The contribution of the available evidence to our understanding of the imaging of this ligament is variable. Given the lack of data from the qualitative arm of the study, as presented in chapter 4, and the variable results presented in this chapter, further consideration of this ligament and the contribution it makes to the progression of PTTD is warranted. Future work on this topic, including any subsequent clinical protocol development, should reflect exploration of the

assessment of the integrity of the CNL, assessing for attenuation and tears of the CNL in relation to PTTD, as well as making recommendations for the most appropriate imaging regime when considering CNL involvement in the presentation of PTTD.

Chapter 6: Kinematic and kinetic characteristics of the single heel rise test and navicular drop and drift in PTTD

Aspects of this chapter have been published

Durrant, B., Chockalingam, N., Richards, P.J., Morriss-Roberts, C., (2015). Posterior Tibial Tendon Dysfunction: What does the single heel raise test mean in assessment? The Foot and Ankle Online Journal, 8(2), 6.
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Abstract accepted for FIP 2016 entitled:

‘Navicular displacement and the single heel rise test in the kinematic assessment of Posterior Tibial Tendon Dysfunction (PTTD). A feasibility study’.

6.1 Introduction

This chapter builds on the work of previous chapters which examined the literature (Chapter 2), and looked at the qualitative work exploring the opinions and beliefs of health professionals (HPs) concerning the assessment and diagnosis of PTTD (Chapter 4).

Various clinical tests have been highlighted as occupying an important place in the opinions and beliefs of clinicians assessing and diagnosing PTTD. Some of these tests have been selected for further exploration. Navicular drop (NDro) and navicular drift (NDri) in participants with PTTD under static and dynamic conditions have been compared to those of control participants. Further, frontal plane rearfoot calcaneal angle and maximum heel heights have been compared for the PTTD pathology group and control group. Additionally, the relationship between NDri and NDro and the variables described thus far have been explored. Finally, foot pressures during the stance phase of gait have been compared between groups. The foot pressure results have been explored and patterns observed with reference to the dynamic NDri and NDro results.

The work presented here discusses findings from kinematic and kinetic data collected for a group of participants with PTTD and a control group. The results have been explained within the context of discussions presented in Chapter 4. The results of such work have not been reported in this manner in the available published literature. The content of this chapter, and those before will contribute previously unreported findings to the body of knowledge emerging in this area.

6.2 Background

Chapter 2 demonstrated a tendency among health care professionals to rely on a number of clinical tests to aid in the assessment and diagnosis of PTTD. This chapter discusses three of the most commonly employed tests:

- Navicular drift test.
- Navicular drop test.
- The single heel rise test.

The chapter investigates how these relate to quantitative kinematic and kinetic observations.

6.2.1 Navicular displacement (NDro and NDri)

Chapter 4 discussed the results of the open ended questions and the focus group responses providing insights into tests that health care professionals cite as being important in the assessment of PTTD. When asked about the core question surrounding the items that should be included in assessment criteria, there were numerous responses referring to the navicular. Terms such as ‘navicular bulging’, ‘navicular drift’, ‘dropped navicular’, ‘navicular sag’, and ‘navicular drop’ were frequently cited, describing observable changes in the assessment of PTTD. These terms were closely linked with the assessment of ‘foot pronation’, ‘assessment of medial longitudinal arch height’, ‘foot collapse’, ‘lowering of the medial arch’, and ‘hindfoot alignment’, ‘rearfoot motion’ and ‘subtalar joint’. There was overwhelming acknowledgement that patients diagnosed with PTTD have obvious and observable changes in foot shape and the terms used to describe this mirror the key words highlighted above.

Evidence suggests that changes in navicular displacement are linked to foot posture (see discussion in Sections 2.10 and 6.8.1). In patients diagnosed with PTTD, the change in foot posture is akin to increased levels of rearfoot pronation at the subtalar joint (Chimenti et al., 2014; Rabbito, Pohl, Humble, & Ferber., 2011), and changes in the medial longitudinal arch profile. When examining the effects of excessive navicular displacement (NDri and NDro), a similar presentation of foot posture is present whereby a pronated foot posture is linked with an increased amount of NDro and NDri (Mueller et al., 1993; Snook, 2001; Spornly-Nees et al., 2011; Vicenzino et al., 2000; Vinicombe et al., 2001).

Since there is strong evidence that navicular displacement in the vertical and mediolateral directions provides a good indicator of rearfoot pronation, it is plausible that a measure of navicular displacement in PTTD may be a useful addition to the assessment of this progressive and painful foot condition.

6.2.2 Single heel rise test

Despite its adoption for assessing the presence of PTTD, the origins of this test are varied. Historically, the heel rise test, also known as the calf rise test, had been utilised to assess posterior muscle strength. It has been utilised in the assessment of various pathologies with its earliest application in the assessment of posterior muscle strength in polio sufferers (Hébert-Losier et al., 2009). Although commonly employed in clinical practice, until recently, this test has not been used to provide empirical quantitative data specifically related to PTTD.

The heel rise test is used to assess static weight bearing muscle function and tendon dysfunction. The test is recommended for individuals with PTTD (Bluman et al., 2007; Houck et al., 2009b; Johnson & Strom, 1989; Myerson & Corrigan, 1996; Otis & Gage, 2001). Weakness of the posterior tibialis muscle is thought to contribute to inability to perform a heel rise task. Clinically, an abnormal heel rise test is observed when the individual cannot perform a heel rise or performs the heel rise and fails to invert the posterior heel on rising (Kohls-Gatzoulis, Angel, et al., 2004a), suggesting that the posterior tibialis muscle is no longer acting to invert the hind foot or that the patient is demonstrating progressive PTTD (Houck et al., 2009a, 2009b).

6.2.3 Kinematic changes during the heel rise test

The weight bearing static heel rise test provides a weight bearing method of assessing posterior muscle strength. In two recent studies investigating the kinematic changes associated with this test (Chimenti et al., 2014; Houck et al., 2009b), researchers in one study (Houck et al., 2009b) revealed that the kinematic changes during a bilateral heel rise test showed a similar pattern to that observed for the non-PTTD control group. During the dynamic heel rise test the kinematics of rear foot eversion in the PTTD group were not found to be significantly different from controls. However, the same study (Houck et al., 2009b), demonstrated a significantly different segmental relationship. That is to say, that while the observable kinematic changes showed similar characteristics in terms of pattern, this was relative to the PTTD baseline (a pronated foot type). Other interesting findings to note relate to first metatarsal function which demonstrated a more dorsiflexed position than the control group, and first metatarsophalangeal joint

dorsiflexion which demonstrated reduced dorsiflexion in the PTTD group. This suggests that first ray function may be a secondary indicator of midfoot function in this group. First ray function, in addition to navicular displacement, could be related to the single heel rise test result.

Notwithstanding the significance of these results, participants in this study (Houck et al., 2009b) were required to perform a bilateral heel rise manoeuvre. The most common method of conducting this test is for patients with PTTD to perform a single heel rise. A single heel rise is preferable to a bilateral heel rise because the contralateral limb could compensate for a loss of function in the ipsilateral limb being tested.

In a more recent study, by Chimenti et al. (2014), investigating age related differences in performing a single heel rise test for Stage II PTTD compared to controls, other factors were highlighted that differ between control and pathology groups. These differences, include, maximum heel height, differences in kinematic rearfoot and forefoot joint motion, increased first ray dorsiflexion and reduced maximal ankle plantarflexion in the PTTD group. Until now these metrics have not been considered when assessing the results of the single heel rise test in PTTD.

The authors (Chimenti et al., 2014) found that participants with reduced heel height during the single heel rise manoeuvre also showed first ray dysfunction compared to controls. In addition, participants were found not to have significantly dissimilar rearfoot eversion when compared to controls during the manoeuvre. This indicates that the desired outcome (inversion of the rearfoot) may not be a significant diagnostic indicator for PTTD. Research suggests that other factors, such as forefoot and mid foot function, should be considered too.

Due to the modelling used in this study (Chimenti et al., 2014) it was not possible to explain in detail the mid foot kinematics. Therefore, the role that NDro and NDri plays in mid foot kinematics during the single heel rise manoeuvre cannot be explained by this study.

The relationship between rearfoot kinematics and navicular displacement has been reported and it is widely accepted that there is a significant relationship between the two

variables (Cornwall & McPoil, 1999; Dahle et al., 1991; Dicharry et al., 2009; Kothari et al., 2014; Loudon, Jenkins, & Loudon, 1996; McPoil & Cornwall, 1996; McPoil et al., 2013; Mueller et al., 1993; Saltzman et al.; Snook, 2001; Vicenzino et al., 2000). It is also accepted that the rearfoot, midfoot, and forefoot kinematics are altered in the presence of PTTD (Houck et al., 2009a; Imhauser, Siegler, Abidi, & Frankel, 2004; Ness et al., 2008; Niki, Ching, Kiser, & Sangeorzan, 2001; Rattanaprasert et al., 1999; J. Tome, D. A. Nawoczenski, et al., 2006). The kinematic profile of the single and bilateral heel rise manoeuvre in the presence of PTTD has recently been reported on (Chimenti et al., 2014; Houck et al., 2009b; Kothari et al., 2014; Kulig, Lee, Reischl, & Noceti-DeWit, 2015). However, the kinematic characteristics between navicular drift and drop in a static and dynamic situation during a single heel rise manoeuvre are unknown. The relationship between the variables, maximum heel height and posterior rearfoot angle during a single heel rise manoeuvre in a static and dynamic situation is also unknown.

The tibialis posterior tendon takes its main distal insertion from the tuberosity of the navicular. The tendon is put under tensile stress as it inverts the foot as the foot progresses into relative plantar flexion on commencement of the test. If the foot fails to invert on rising, pathology of the tendon is thought to exist. If the foot fails to invert, the navicular would be less likely to retain its position due to the lack of concentric contraction of the muscle belly on rising. This may then allow the navicular to 'drift' or 'drop' medially. As the single heel rise is used to aid the diagnosis of dysfunction of this tendon, it seems logical that the single heel rise test and the position of the navicular would be related with regard to PTTD. However, there is a paucity of published data to support this assertion.

6.2.4 Foot pressure assessment and its relationship to navicular displacement

Foot pressure assessment provides valuable information about changes in pressure distribution and force that have occurred in the presence of foot pathology. There have been several investigations detailing the insights gained from using such assessment. Dynamic foot pressures have been used to characterise foot function (H. B. Menz, Munteanu, Zammit, & Landorf, 2010; S. Rao, Baumhauer, & Nawoczenski, 2011) and have been linked to foot pathology including PTTD (Imhauser et al., 2004). Likewise navicular

displacement has been linked to both foot function and foot pathology (Dicharry et al., 2009; Jonely, Brismée, Sizer Jr, & James, 2011; Kappel et al., 2012; Kothari et al., 2014; Mueller et al., 1993). However, the relationship between navicular displacement and foot pressures in PTTD have never been investigated. There is little research that specifically deals with foot pressure changes in PTTD.

Therefore, this chapter will further the scientific understanding of the kinematic changes associated with PTTD in relation to the NDro and NDri, the single heel rise manoeuvre, and foot pressures in participants with PTTD compared to control participants.

6.2.5 Multi-segment analysis in foot kinematic analysis

Since the emergence of three-dimensional motion analysis, various methods and foot models have been proposed for capturing foot and ankle kinematics (see Chapter 2 for the discussion relating to this). For this study, the foot model employed to capture static and dynamic kinematic data is the Istituto Ortopedico Rizzoli (IOR) foot model developed and validated in 1999 (Leardini et al., 1999a) and modified in 2007 (Leardini et al., 2007). This model was chosen because it has shown good reliability and repeatability for both normal and pathological feet (Arnold, Mackintosh, Jones, & Thewlis, 2013; Deschamps, Staes, Bruyninckx, Busschots, Jaspers, et al., 2012; Deschamps, Staes, Bruyninckx, Busschots, Matricali, et al., 2012). The IOR marker foot model was also the default model used at the biomechanics laboratory where the data was collected.

For all of the reasons above, the modified marker placement set for the IOR foot model (Leardini et al., 2007) was adopted for this study (see Figure 20). This marker set provides a rearfoot, midfoot and forefoot multi-segment model for data acquisition and subsequent analysis.

Although NDro and NDri have been investigated in both static and dynamic situations, and have been explored in relation to pathology (Dicharry et al., 2009; Loudon et al., 1996; Saltzman et al.; Snook, 2001), there are currently no reports that have investigated these tests in relation to PTTD. Furthermore, there are no reports linking NDro and NDri in relation to other commonly employed tests identified by this research.

Single heel rise tests have been repeatedly cited as aiding clinical diagnostic and assessment understanding of PTTD (Bluman et al., 2007; Houck et al., 2009a, 2009b; Johnson & Strom, 1989; Kohls-Gatzoulis, Angel, et al., 2004b; Kulig et al., 2015; Menz et al., 2003; Otis & Gage, 2001). Despite this, there is little empirical evidence that these tests are robust and fit for purpose. Similarly, there is little information on how they relate to the results of other tests such as NDro and NDri. There is also scant evidence of the investigation of foot pressures in this patient group.

This study hypothesised: first, that dynamic NDro and dynamic NDri would be similar for the PTTD group and the control group; second, that dynamic foot pressures/force (contact pressure, peak force, and peak contact pressure and contact area) during the stance phase of gait for the PTTD compared to the control group would be similar; third, that the relationship between the frontal plane calcaneal angles, when comparing the calcaneus to the shank segment during a single heel rise manoeuvre, would yield similar results for the PTTD group and the control group; and finally, that heel height characteristics of the single heel rise test in participants with PTTD compared to the control group would be similar.

6.3 Aims

The aims of this study were to:

1. Establish whether the single heel rise test and navicular displacement could be used to differentiate between PTTD participants when compared to controls, thereby aiding assessment and diagnosis of PTTD.
2. Determine if foot pressure assessment could be utilised to provide kinetic observations in participants with PTTD that differed from observations of control participants.

Therefore, the research questions for this arm of the study were:

1. What are the kinematic characteristics of dynamic navicular displacement in participants with PTTD compared to those of controls?
2. What is the relationship between navicular displacements during the single heel rise test in participants with PTTD compared to that for controls?

3. What is the relationship between dynamic foot pressures and dynamic navicular displacement in participants with PTTD compared to that for controls?
4. What is the relationship between rearfoot frontal plane calcaneal angle and heel heights during a single heel rise manoeuvre in participants with PTTD compared to that for controls?

In conducting this study, two of the three principal research questions (see 1.4) will be partially addressed:

1. Do the kinematic and kinetic changes associated with clinical assessment tests for PTTD reflect interdisciplinary opinions and beliefs identified through qualitative exploration of questionnaire and focus group discussion data?
2. What contribution does interdisciplinary consultation make to the exploration of assessment approaches for PTTD with a view to clinical protocol development?

6.4 Objectives

The objectives of this study were to:

1. Compare maximum heel height and rear foot angle for a unilateral heel rise test in PTTD with control participants.
2. Determine the dynamic mediolateral and vertical displacement patterns of the navicular for stance phase duration in PTTD and compare with controls.
3. Determine the dynamic mediolateral and vertical displacement patterns of the navicular during a unilateral heel rise test in PTTD and compare with controls.
4. Compare peak pressure, contact pressure, and peak contact pressures during the stance phase of gait in PTTD with control participants.

6.5 Methods

6.5.1 Participants

Prior to data collection, participants were required to provide consent for participation in the study (see Appendix 12.10). Five participants diagnosed with Stage IIPTTD, as defined by the classification systems currently used in clinical practice, were recruited to the study. Five age matched controls were recruited. Each participant's height and weight

was recorded and foot posture assessed using the validated foot posture index (FPI 6) (Redmond, Crosbie, & Ouvrier, 2006). All participants with PTTD were grouped as displaying a pronated foot posture. All control participants were grouped as displaying a neutral foot posture.

6.5.2 Inclusion criteria

For the pathology group, the inclusion criteria for the study were: a unilateral diagnosis of PTTD; no other co-morbidities; no recent history of co-morbidities, surgical intervention or other undiagnosed symptoms; between 40 and 60 years of age; able to mobilise independently; and on screening have a pronated foot type as classified by the foot posture index.

Inclusion criteria for the control group stipulated that participants must be: between the ages of 40 and 60; a-symptomatic and free from any underlying diagnosed pathology; and when assessed for foot posture demonstrate a neutral foot type. Since these participants were free from pathology, they self-selected their dominant foot by answering the question “which foot would you use to kick a ball?”

Five control participants were selected from a university population of students and staff. This provided two independent groups for data collection and further statistical analysis. This gave a sample of 5 in the pathology group and 5 in the control group, giving a total sample size of 10.

6.6 Protocol

6.6.1 Equipment and marker placement protocol

Trajectories for each of the segments described below were captured using an 18 camera three-dimensional (3D) motion analysis data capture system (Vicon Motion Systems Ltd., Oxford, UK), and two AMTI force-plates (AMTI, Watertown, MA), both operating at 100Hz.

The IOR multi-segment foot model (Leardini et al., 2007; Leardini, Benedetti, Catani, Simoncini, & Giannini, 1999b) was employed for the kinematic data collection and subsequent analysis. This is a multi-segment model comprised of rearfoot, midfoot, and forefoot segments. It benefits from ease of navicular identity since this marker forms part of the mid foot section, and therefore was the model of choice for this study. Furthermore, the IOR foot model has been previously used to study the low arch foot (Powell, Long, Milner, & Zhang, 2011) and is therefore deemed the best model for PTTD observations.

Marker placement followed that recommended by Leardini et al. (2007), identifying four segments. The shank utilised 9.5mm passive reflective markers placed on the tibial tuberosity, the head of fibular, and the medial and lateral malleoli. The rearfoot segment had 9.5mm markers placed on the posterior aspect of the calcaneus (two markers were used; superior = CA, inferior = CAB), the sustentaculum tali and the peroneal tubercle. The midfoot segment utilised 9.5mm markers placed on the tuberosity of the navicular, and the base of the 1st, 2nd and 5th metatarsals. Finally, the forefoot segment had markers placed on the head of the first metatarsal and the dorsomedial aspect of the proximal phalanx, the head of the second metatarsal, and the head of the fifth metatarsal (see Figure 22).

Foot pressures were collected using a walkway system (Tekscan, Boston, MA). Data was captured at 100Hz. The mat consisted of four high resolution mats organised in a single walkway allowing multiple step data capture. Resolution was equal to 3.9 sensors per cm². The walkway had an overall length of 5.4 metres and a width of 1.9 metres.

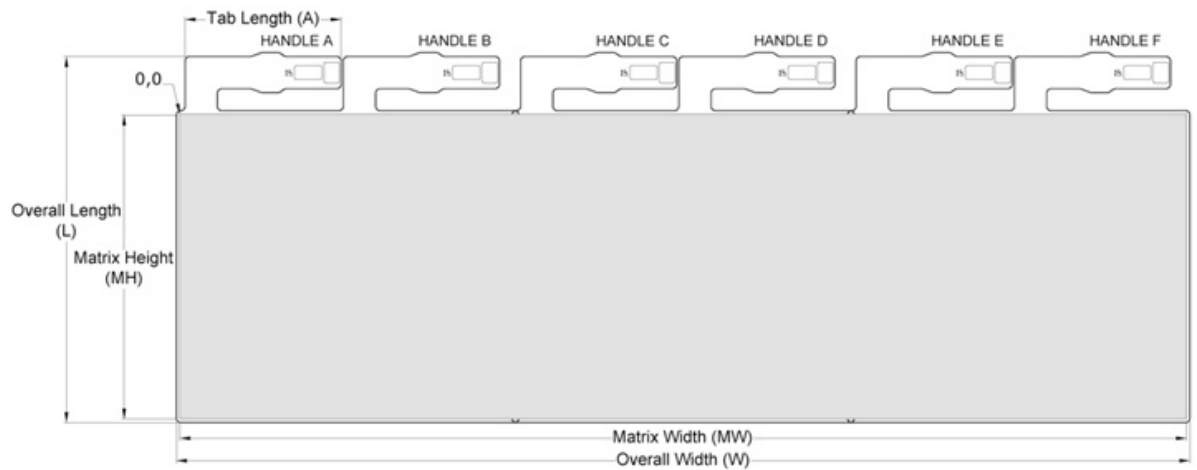


Figure 20: Image illustrating the walkway provided by the manufacturer (Tekscan, Boston, MA).

6.6.2 Data collection protocol

The checklist found in Appendix 12.9 was used to ensure consistency in the data collection procedure.

The gait analysis protocol had three sections. For each section, participants were required to repeat the task three times:

1. Participants were required to stand in relaxed stance, on the force plate, in order to collect baseline static trial data.
2. Next, participants were asked to rise up onto the toes on one foot at a time (the single heel rise manoeuvre). They were permitted fingertip support to perform the single heel rise. The protocol for this procedure has been previously described in the literature (Chimenti et al., 2014; Houck et al., 2009b), and this method was adopted for this study.

The recommendations provided by (Hébert-Losier & Holmberg, 2013) were adopted when conducting the single heel rise test. The points to note are as follows:

- Ankle starting position, i.e. position of the foot in relation to the tibia: All participants were asked to stand in relaxed standing and this was used as the baseline measure.
 - Knee starting position (flexion/extension): Participant's knee was in full extension at the beginning of all the trials.
 - Pace (rises/min): Participants self-selected the time taken to complete the manoeuvre. It was important for participants with PTTD that they were able to take as much time as needed to carry out the task.
 - Balance support, e.g. fingertip support: This was allowed for all participants and followed the protocol by Chimenti et al. (2014).
 - Termination criteria, e.g. pain, unable to maintain, fatigue etc.
3. Finally, participants were asked to walk the length of the laboratory data capture zone, first walking across two force plates, capturing left and right foot heel strike and toe off, and second, walking in the opposite direction to capture foot pressure data from the walkway. (The dynamic trial).

All data was collected assuming a right hand coordinate system (see Figure 21), whereby the vertical component is in the Z direction where positive is superior, the mediolateral is the Y direction where positive Y is to the left, and anterior posterior is X where positive X is in the direction of travel.

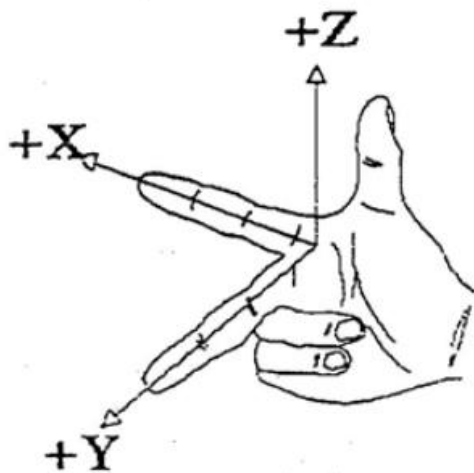


Figure 21: Right hand global coordinate system used in this study.

6.7 Data processing

For this study dynamic NDro is defined as the vertical (Z) displacement of the navicular during the stance phase of gait from heel strike to toe off.

Dynamic NDri is defined as the mediolateral (Y) displacement of the navicular during the stance phase of gait from heel strike to toe off.

Static NDro is defined as the vertical displacement (Z) of the navicular observed while conducting a single heel rise manoeuvre.

Static NDri is defined as the mediolateral displacement (Y) of the navicular observed while conducting a single heel rise manoeuvre.

Static maximum heel height is defined as the maximum vertical distance between the posterior calcaneal heel marker (CAB) and the supporting surface during the heel rise manoeuvre.

All kinematic data was initially processed using Nexus version 1.8.5. All trials were reconstructed using the reconstruction pipeline function. All markers were identified using the IOR marker placement foot model template.

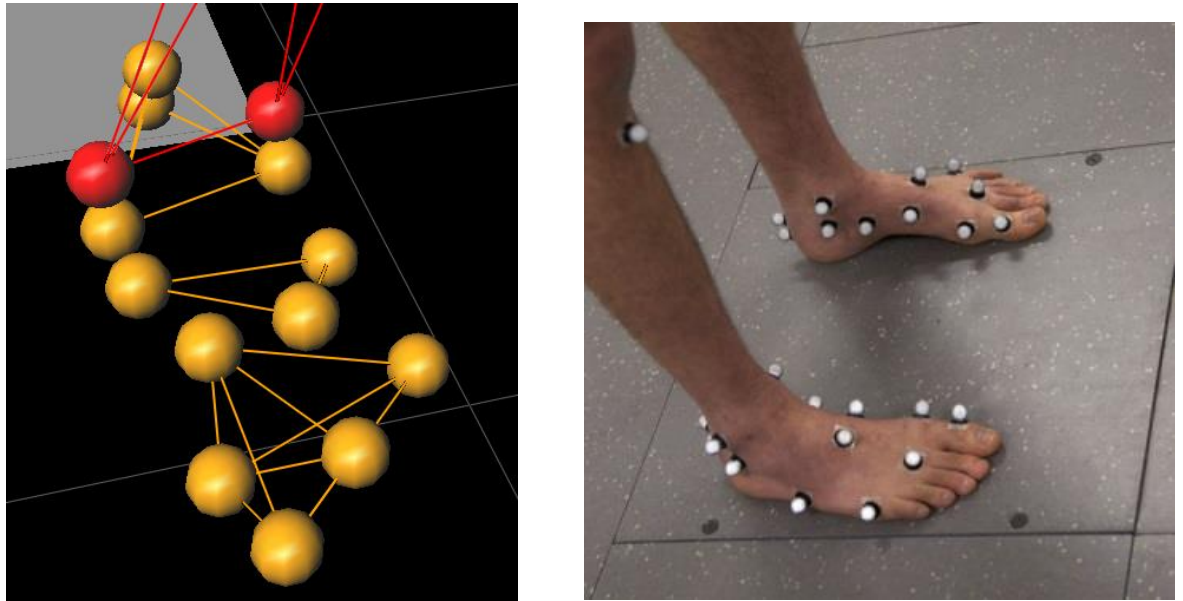


Figure 22: Image illustrating the marker placement used for the IOR multi-segment foot model.

Any unlabelled trajectories were identified and all gaps filled. Once all trials were processed, identification of gait events for heel strike and toe off for each trial for each participant was completed. Next, the processed files were exported for further analysis in visual 3D.

All files were saved and reimported into Visual 3D in the C3D format. Once imported the model template was attached to the static file calibration files. The template used was the modified IOR foot model (Portinaro, Leardini, Panou, Monzani, & Caravaggi, 2014). This updated the 2007 model (Leardini et al., 2007), adding an additional calcaneal marker and improving the reliability of data capture of the medial longitudinal arch and the first metatarsophalangeal joint. The authors postulate that the revised marker placement and foot model configuration offers enhancements for those wishing to investigate the development of gait in children and the diagnosis of flexible flat foot (Portinaro et al., 2014). Therefore, this was deemed the best choice of foot model for the population studied here.

Once attached, the model was appended to all dynamic trials. Data defining three dimensional displacement of the navicular (X, Y, Z) was achieved using a specifically designed pipeline script. The same pipeline was applied to the static single heel rise trials.

6.7.1 Pipeline details

The pipeline utilised the standard IOR foot model coordinates with some modifications to the standard model to allow the desired analysis. The modified model added a kinematic segment detailing the coordinates used in determining navicular displacement. The additional landmark, 'RTN_projected', defined the vector used in navicular displacement. This additional information allowed navicular displacement 'drift anatomical' to be identified and the resulting data to be exported as text files which were later reimported to Excel for further analysis. Additional pipelines were used to determine planar angles for the calcaneus relative to the shank. The pipeline utilised the 'model_based_data computation' function to define the segments included in the computation. The 'event_global_maximum' and 'event_global_minimum' functions allowed maximum and minimum heel heights to be calculated.

6.7.2 Verification of the modified model capturing directional displacement for NDri and NDro

First, a pseudo IOR foot model was constructed in the Vicon data capture zone. The navicular marker was then moved in three directions representing the X, Y and Z components (Figures 23 and 24).

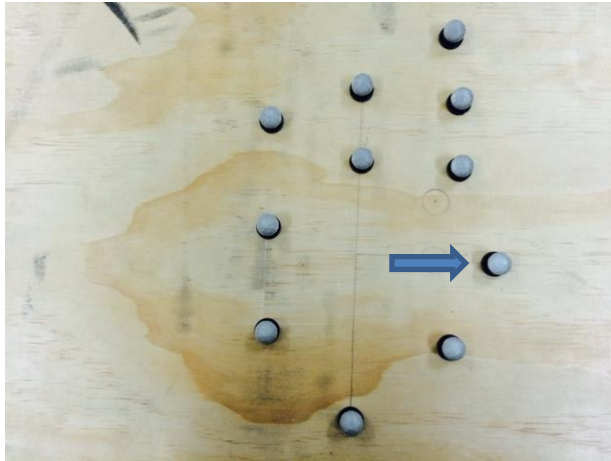


Figure 23: Pseudo IOR model set-up with the navicular marker displaced medially.

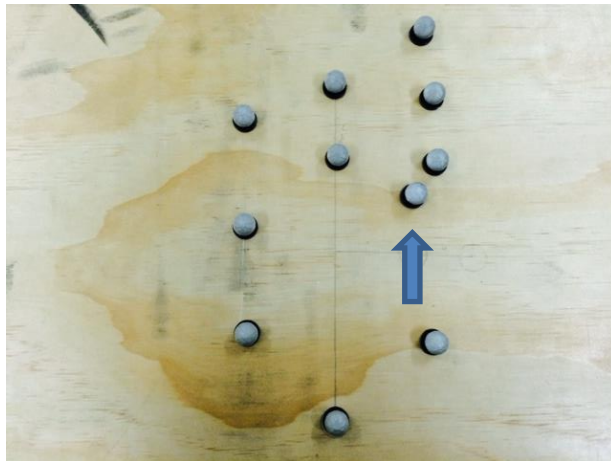


Figure 24: Pseudo IOR model set-up with the navicular marker displaced anteriorly.

Verification of the direction of movement for NDri and NDro was achieved by collecting a series of trials where the navicular marker was moved in three directions, X, Y, and Z. This data was then processed and the C3D files were imported to Visual 3D.

Once imported the data was graphed and the data values analysed to confirm directional displacement of X, Y, Z. By moving the RTN target in the X, Y, and Z directions, the resulting graphs and data points are used to determine direction (Figures 25 and 26 show the set-up of these trials).

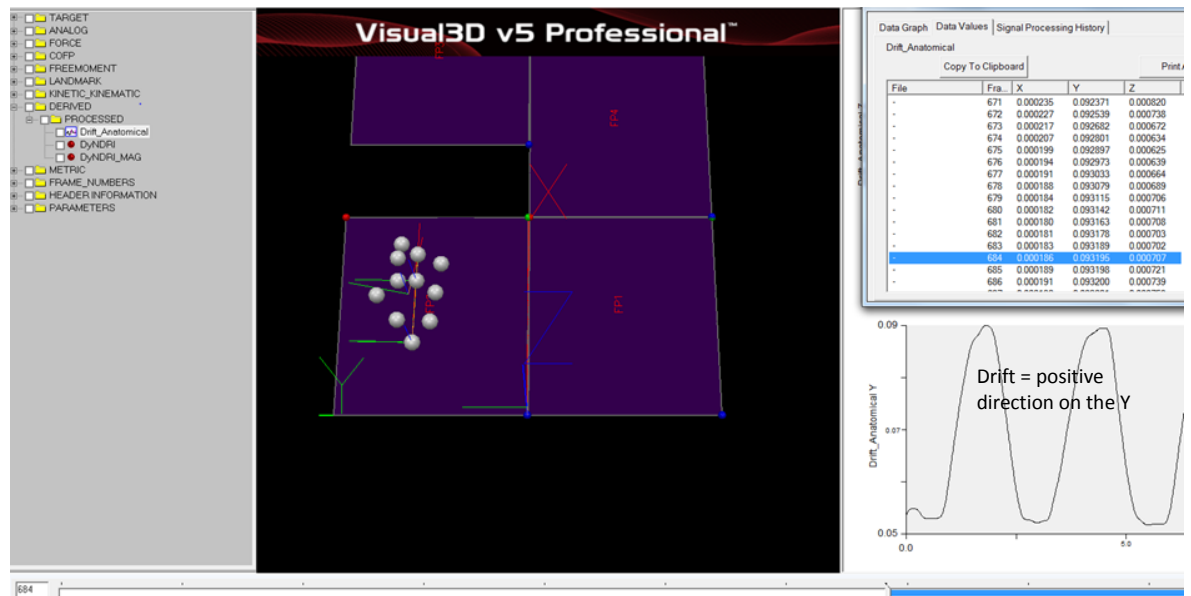


Figure 25: Graphical display of navicular drift and the corresponding data points and data capture view for the Y component.

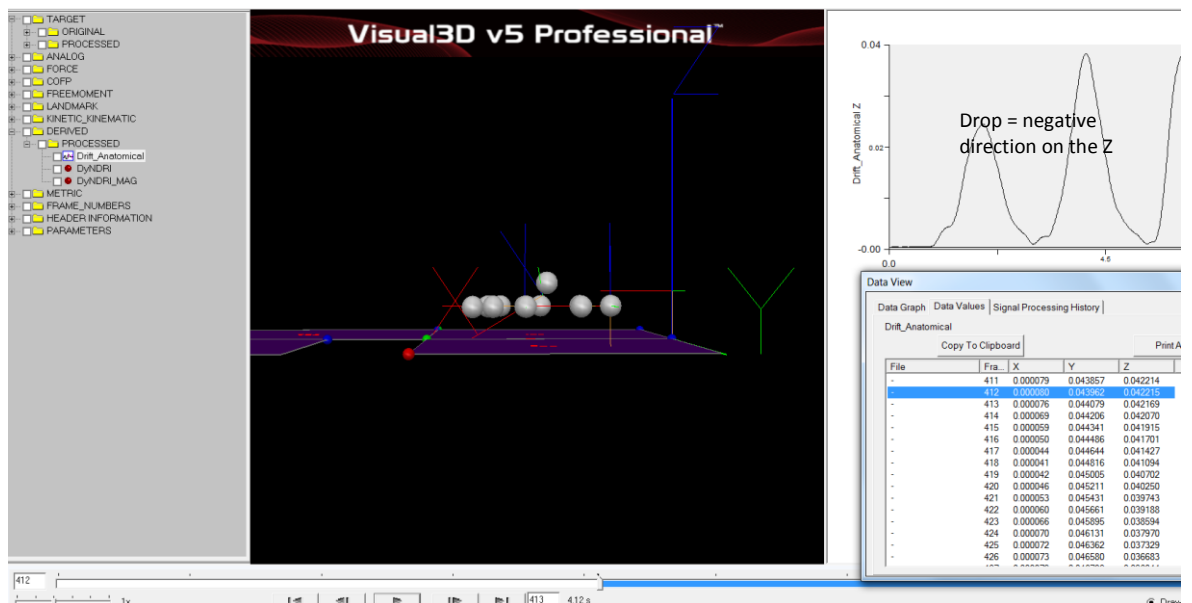


Figure 26: Graphical display of navicular drop and the corresponding data points and the data capture view for the Z component.

This process confirmed the directional movement of the modified IOR model incorporating NDri and NDro. The model was applied to all C3D files for dynamic and static trials. This enabled dynamic and static navicular drop and drift to be analysed across the data set for participants in the pathology group and the control group.

All data was filtered using a 6Hz Butterworth filter which is the standard filtering technique. The resulting processed data was exported as text files and reimported to Excel and SPSS for statistical analysis (see Sections 6.7,6.8 and 6.9).

6.7.3 Foot pressure data processing

The foot pressure data was initially processed by the walkway software (Version 7.0.2.). Each trial was processed using the 'strike box' and 'template' functions. The template, when applied, divides the foot into 13 regions as follows.

Table 6: Regions of the foot identified following application of template and strike boxes.

1)	TF: Total foot
2)	MH: Medial heel
3)	LH: Lateral heel
4)	MF: Midfoot
5)	M1: 1 st metatarsal
6)	M2: 2 nd metatarsal
7)	M3: 3 rd metatarsal
8)	M4: 4 th metatarsal
9)	M5: 5 th metatarsal
10)	T1: 1 st toe
11)	T2: 2 nd toe
12)	T3: 3 rd toe
13)	T45: 4 th and 5 th toe

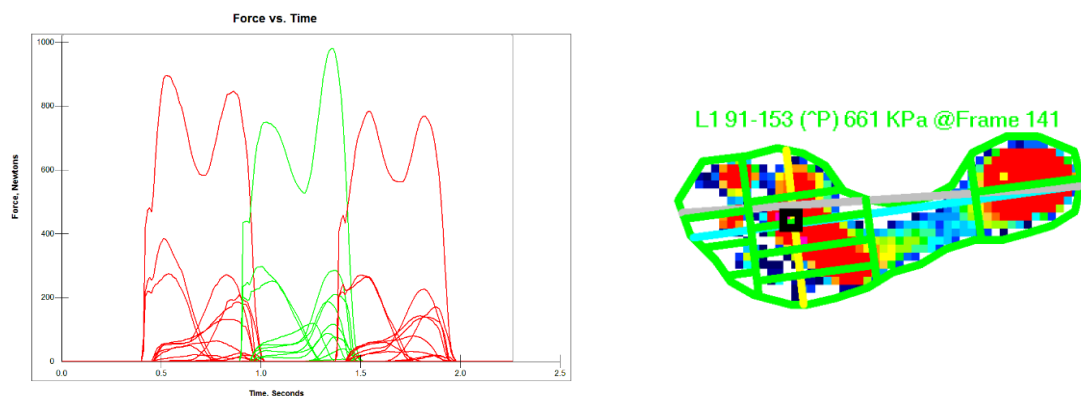


Figure 27: Example of foot strike with template in situ and resulting graphical display.

Once all the trials had been processed in this way, the resulting data for peak force, force, contact area, contact pressure, and peak contact pressure were exported as ASCII files for further processing.

The exported data provided 101 data points for each file (participant trial) for each of the 13 areas. This data was then reduced by producing the peak values for each of the 13 regions, for each participant trial. This information was then used for further processing in SPSS (discussed in Section 6.10).

6.8 Statistical analysis

Statistical analysis was executed using IBM SPSS v22. The distribution and variance of the data was first explored utilising frequency distributions, histograms and Q-Q plots. The data was tested for parametric suitability using the Kolmogorov-Smirnov (KS) test (see Section 6.8 for the results of these tests). The results of this covariance analysis confirmed the data to be suitable for further non-parametric testing. The test employed for the remaining analysis was the Mann-Whitney U test. This test was chosen since it represents the non-parametric equivalent to the independent t test. The independent variables were identified as the condition (either PTTD or control) and the dependent variables were the dynamic or static kinematic NDri or NDro data, the foot pressures and the heel heights.

6.9 Results for distribution and normalcy of data

6.9.1 Navicular drift and drop

The results of the Q-Q plots for both the control and pathology data suggest that the distribution and normality of the data is suited to non-parametric statistical analysis.

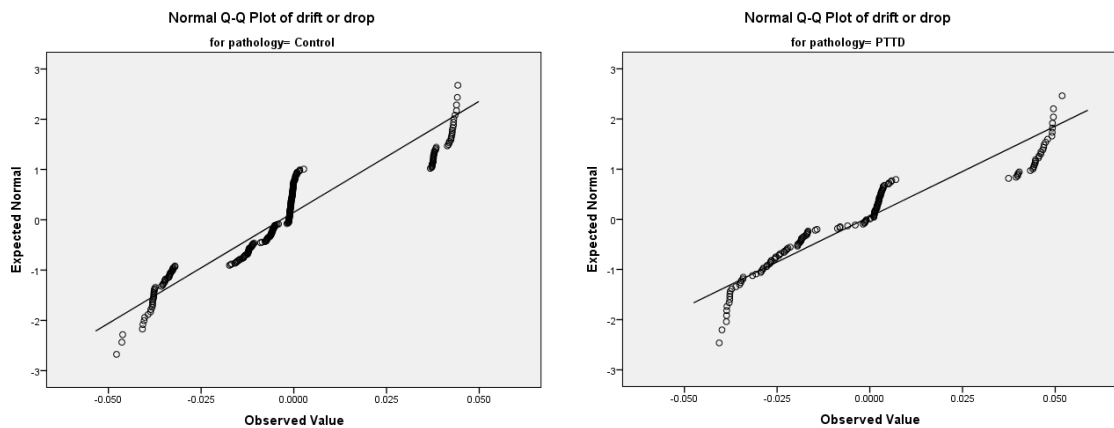


Figure 28 and Figure 29: Graphs which demonstrate non-normal data, therefore confirming that the non-parametric Man Whitney U test is the most suitable test for the data.

Table 7: Normality of kinematic data for navicular drift and drop for PTTD and control participants.

Tests of Normality							
	Group	Kolmogorov-Smirnov (KS)			Shapiro-Wilk (SW)		
		Statistic	df	Sig.	Statistic	df	Sig.
Drift or drop	Control	.256	267	.000	.872	267	.000
	PTTD	.180	144	.000	.888	144	.000

The table above confirms that both K-S and the S-W tests for both navicular drift and drop control and PTTD groups demonstrate significant results. For the K-S results for the control group $D(267) = 0.256$, $p < .001$, and for the PTTD group $D(144) = 0.180$, $p < .001$, and for the S-W test for the control group $D(267) = 0.872$, $p < .001$, and for the PTTD group $D(144) = 0.888$, $p < .001$. This suggests that the data is significantly non-normal. Therefore, the non-parametric Mann-Whitney U test was employed for the remaining analysis.

6.9.2 Heel rise data

The results for the Q-Q plots and histograms for both the control and pathology data suggest that the distribution and normality of the data is suited to non-parametric statistical analysis. Further analysis with K-S and S-W tests suggests that the single heel rise data is significantly non-normal.

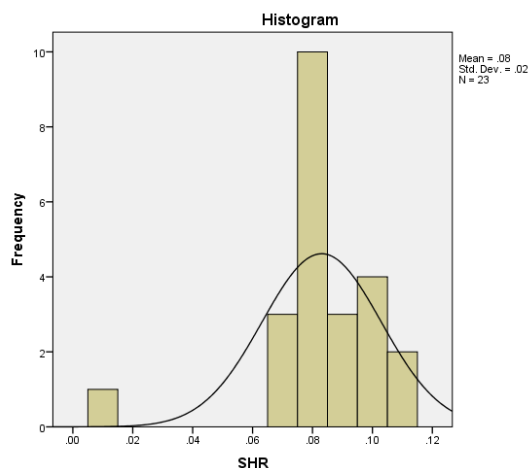


Figure 30: Frequency histogram of single heel rise results.

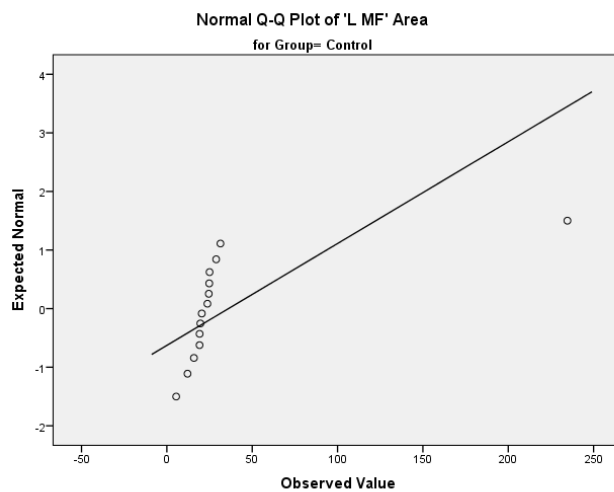
Table 8: Distribution and frequency of heel rise data for control and PTTD participants.

Tests of Normality							
	Group	Kolmogorov-Smirnov (K-S)			Shapiro-Wilk (S-W)		
		Statistic	df	Sig.	Statistic	df	Sig.
SHR	PTTD	.334	10	.002	.695	10	.001
	Control	.242	13	.036	.898	13	.027

For the K-S result the control group $D(13) = 0.242$, $p=0.036$ and for the PTTD group $D(10) = 0.334$, $p=0.002$. For the S-W result the control group $D(13) = 0.898$, $p=0.027$, and for the PTTD group $D(10) = 0.695$, $p=0.001$. These results demonstrate that the data for the single heel rise test is significantly non-normal.

6.9.3 Foot pressure data

The results for the heel rise data demonstrate a significantly non-normal distribution for the control group and a normal distribution for the pathology group. Due to there being a large number of data results for this data set only the significant results are displayed in the following sections (6.9.9). The frequency distributions presented here reflect the data presented below.



Contact area. For this variable K-S and S-W results demonstrate significant non-normal data.

Figure 31: Contact area for the midfoot for the control group.

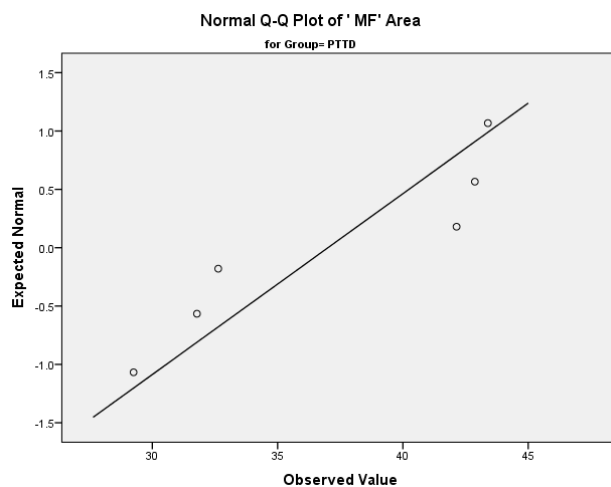


Figure 32: Contact area for the midfoot for the PTTD group.

Table 9: Distribution and frequency for midfoot and second metatarsal area in control and PTTD participants.

Tests of Normality							
	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
'MF' Area	Control	.461	14	.000	.406	14	.000
	PTTD	.287	6	.134	.818	6	.084
'L M2' Area	Control	.529	14	.000	.307	14	.000
	PTTD	.282	6	.147	.888	6	.309

Table 10: Distribution and frequency of data for contact pressure for PTTD and control participants.

Tests of Normality							
	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
'L M5' Area	Control	.147	15	.200*	.956	15	.630
	PTTD	.321	6	.054	.762	6	.026
'L T1' Area	Control	.272	15	.004	.872	15	.037
	PTTD	.284	6	.141	.820	6	.089
'L T3' Area	Control	.208	15	.079	.922	15	.208
	PTTD	.212	6	.200*	.899	6	.366

These results demonstrate that the control group is significantly non-normal for both the midfoot and the metatarsal head two area. For the midfoot area for the K-S test for the control group $D(14) = 0.461$, $p < 0.001$, and for the S-W test for the control group $D(9) = 0.406$, $p < 0.001$. For the metatarsal head two area for the control group K-S, $D(14) = 0.529$, $p < 0.001$ whilst the S-W result for metatarsal head two area for the control group reveals that $D(14) = 0.307$, $p < 0.001$. The results for the pathology group demonstrate a normal distribution. For the mid foot area for the PTTD group $D(6) = 0.287$, $p = 0.134$, and for the S-W test for the PTTD group $D(6) = 0.818$, $p = 0.084$. For the metatarsal head two

area for the PTTD group the K-S result were $D(6) = 0.282$, $p = 0.147$, and for S-W the PTTD group results were $D(6) = 0.888$, $p = 0.309$. Since the analysis needs to reflect the least robust data set, a non-parametric analysis was executed of the remaining data set.

6.9.4 Contact pressure

The table above describes both data that is significantly non-normal in its distribution and data that is normally distributed. By way of example, the following Q-Q plots reflect the results in Table 10.

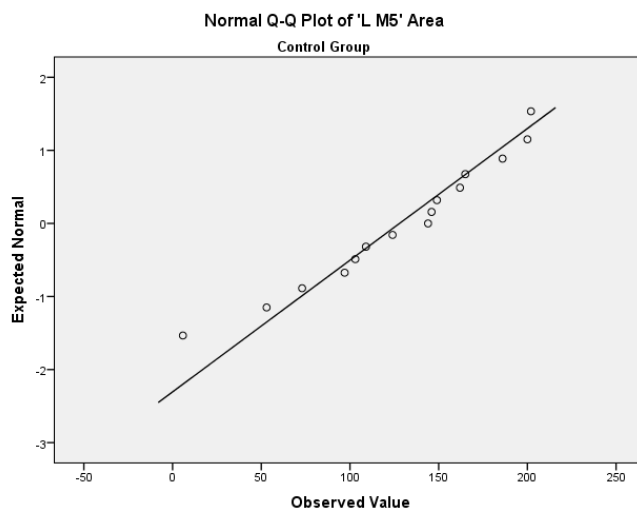


Figure 33: Distribution plots for metatarsal head five area for the control group.

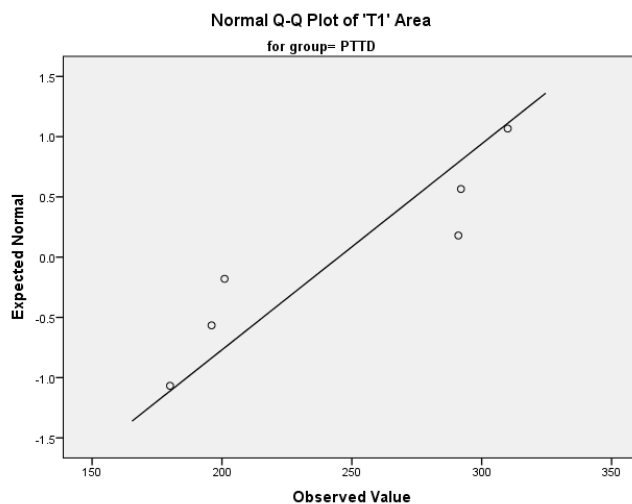


Figure 34: Distribution plot for first toe area for the PTTD group.

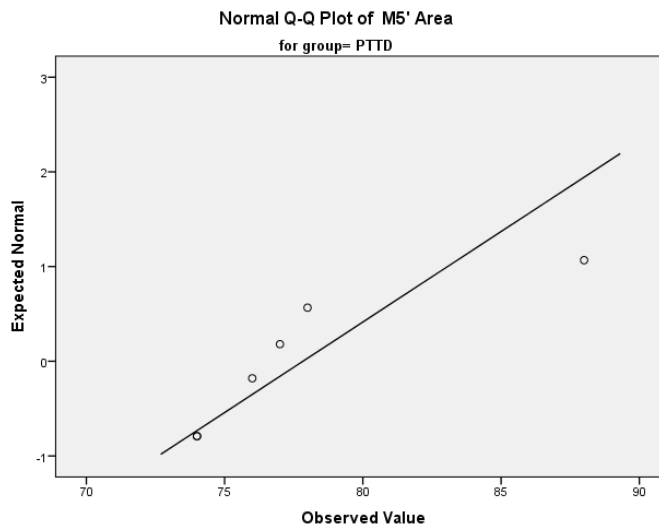


Figure 35: Distribution plot for metatarsal head five area for the PTTD group.

The K-S result for metatarsal head five area for the control group shows there is no significant difference between the observed and expected outcome and therefore this suggests that the data is normally distributed. The result shows $D(15) = 0.147$, $p = 0.200$. For the PTTD group the reverse is true where $D(6) = 0.321$, $p = 0.054$. For the first toe area for the control group $D(15) = 0.272$, $p = 0.004$, indicating a significantly non-normal distribution of data. For the PTTD group $D(6) = 0.284$, $p = 0.141$ indicating a normal distribution of data. For the third toe area both the control group and the PTTD group demonstrate a normal distribution where, for the control group $D(15) = 0.212$, $p = 0.200$ and for the PTTD group $D(6) = 0.212$, $p = 0.200$.

For the S-W result for metatarsal head five area for the control group $D(915) = 0.956$, $p = 0.630$ indicating a normal distribution, whereas for the PTTD group the reverse is true where $D(6) = 0.762$, $p = 0.026$, indicating a significantly non-normal distribution. For the first toe area, the control group demonstrates $D(15) = 0.872$, $p = 0.037$ indicating a significantly non-normal distribution and for the PTTD group $D(15) = 0.820$, $p = 0.089$, indicating a normal distribution. For the third toe area, for the control group $D(15) = 0.922$, $p = 0.208$, and for the PTTD group where $D(6) = 0.899$, $p = 0.366$, both suggest a normal distribution.

6.9.5 Peak contact pressure

The distribution of the data for the metatarsal head area, left and right foot, for peak contact pressure is displayed below. Table 11 illustrates a mixed outcome of the K-S test and the S-W test. However the Q-Q plots demonstrate similar finding. That is that the data shows some kurtosis and skewed characteristics, in addition to being non- normally distributed.

Table 11: Distribution and Frequency of data for Contact area for PTTD and Control Participants.

Tests of Normality							
	group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
'L M3' Area	Control	.238	12	.058	.824	12	.018
	PTTD	.402	6	.003	.695	6	.005
'R M3' Area	Control	.198	12	.200*	.934	12	.429
	PTTD	.270	6	.195	.833	6	.115

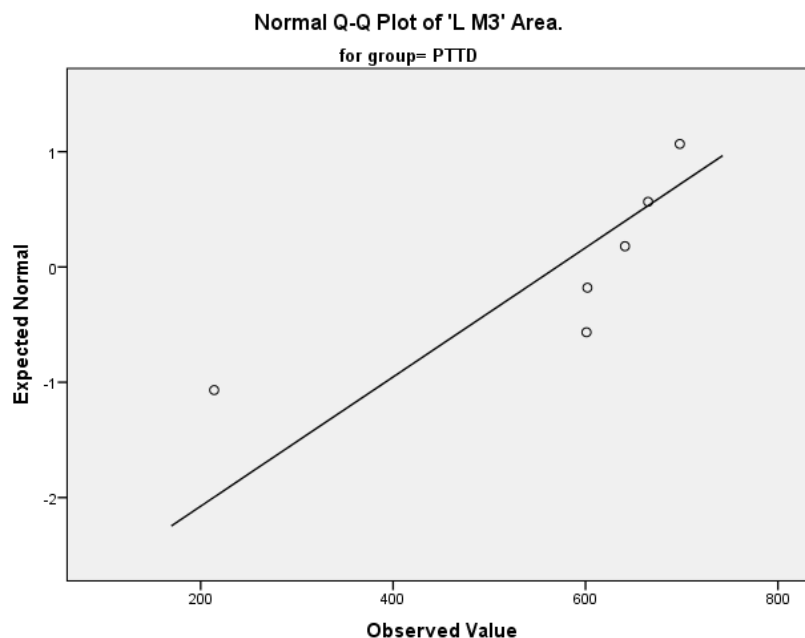


Figure 36: Distribution plot for metatarsal head three area for the PTTD group.

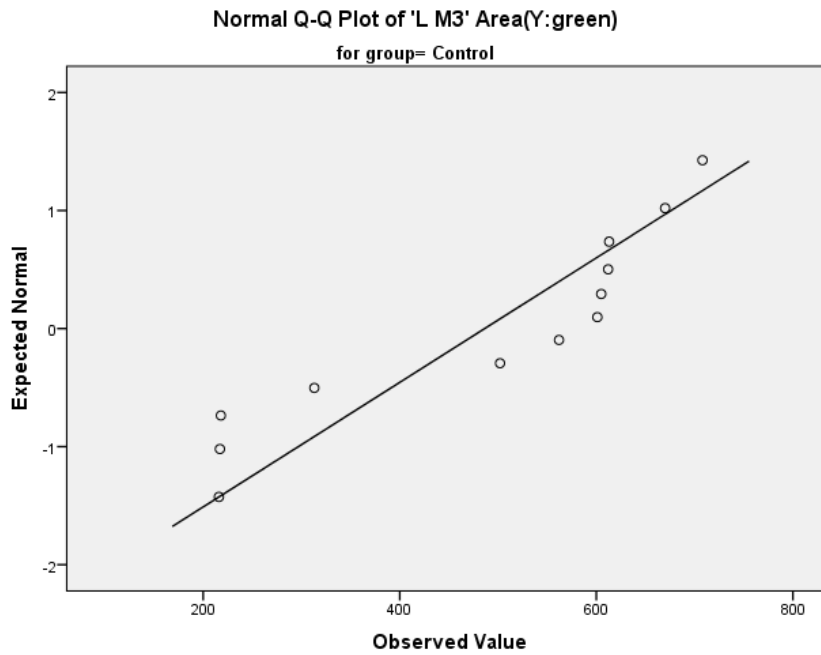


Figure 37: Distribution plot for metatarsal head three area for the control group.

For the left foot metatarsal head three area for the control group the K-S result indicates a normal distribution where $D(12) = 0.238$, $p = 0.058$. For the right foot $D(12) = 0.198$, $p = 0.200$, also indicating a normal distribution. For the left foot control group, the S-W test reports $D(912) = 0.824$, $p = 0.018$, indicating a significantly non-normal distribution. For the right foot S-W test, the test result is reversed, with $D(12) = 0.934$, $p = .429$, indicating a normal distribution. For the PTTD group the K-S result for the left foot suggests a significantly non-normal distribution where $D(6) = 0.402$, $p = 0.003$ and for the right foot $D(6) = 0.270$, $p = 0.195$, indicating a normal distribution. For the S-W test for the left foot, $D(6) = 0.695$, $p = 0.005$, indicating a significantly non-normal distribution, and for the right foot $D(6) = 0.833$, $p = 0.115$, indicating a normal distribution.

6.9.6 Summary of statistical analysis for distribution and normalcy of data

Although the results presented here, with regard to the normalcy of the data, are mixed, non-parametric tests were used on all data sets. This is justified by the fact that the Q-Q plots demonstrate both kurtosis and skewed data. This is supported by the histogram results. In this situation the data can sometimes be transformed to deal with heterogeneity. However, given that the Q-Q plots indicate that there is both kurtosis and skewness of the data and that the sample size is small, and the standard error greater than 1.96 in all cases, it was deemed appropriate to use a less robust method of analysis (Field, 2013) p170-201) in order to reduce the risk of type 1 errors.

6.9.7 Results and statistical analysis for the dynamic NDri and NDro comparing PTTD and control group participants

The statistical analysis for dynamic navicular displacement comparing the PTTD group and the control group during the stance phase of gait demonstrated that participants with PTTD dynamic navicular displacement did not differ significantly from the control group. Comparing the PTTD and control groups $U=21.031$, $SE=14.148$, $p=0.112$.

Navicular displacement for the X, Y and Z components is displayed below in Figures 38, 39 and 40. The results are normalised to 100% of the stance phase of gait.

Statistical analysis for navicular displacement comparing the PTTD group with the control group during a single heel rise test demonstrates that participants with PTTD did not differ significantly from the control group. This is evidenced by the Man-Whitney U test result comparing the two groups where $U=21.23$, $SE=1.15$, $p=0.103$.

Navicular displacement during the single heel rise manoeuvre for the Y and Z components (NDro and NDri) is displayed in Figures 42-45.

Participants with PTTD demonstrated increased pressures in a number of regions identified by the application of the auto template which divides the foot into 13 regions for analysis. Of those 13 regions the forefoot and mid foot demonstrated significant differences in peak pressure, contact pressure and contact area. The most notable difference and arguably the region most likely to expect significant differences in PTTD

was the mid foot. Participants with PTTD showed significantly different mid foot contact area and contact pressure characteristics to the control group.

For the midfoot area, the PTTD group demonstrated significant differences ($p=0.002$) where there was an increase in the foot pressures in this region (see Figure 57). The most obvious explanation for this difference would be the expected lowering of the medial longitudinal arch; a common sign in PTTD. However, these results do not tally with two other measures used in the assessment of an abnormally pronated foot. The kinematic changes seen for NDri and NDro did not demonstrate concomitance with the foot pressure results. Since the data was collected simultaneously any changes seen in NDri and NDro would be linked to the profile of the arch. Likewise, if there is a change in the midfoot region, as shown by these results, there would be an expected change in the total contact area of the foot. This was clearly seen statistically ($p=0.039$) and graphically (see Figure 55) for this data set.

For the purposes of clarity, in clinical practice the terms navicular drop and drift are used to describe sagittal plane drop of the navicular and transverse plane drift of the navicular. Clinically these terms do not take into account the drift component being a result of both X and Y coordinates. Where displacement for the Y component is referred to herein, this is reporting the resultant navicular displacement in Y only. Therefore for the purposes of reporting the data here, the clinical term drift is used interchangeably with displacement on the Y axis.

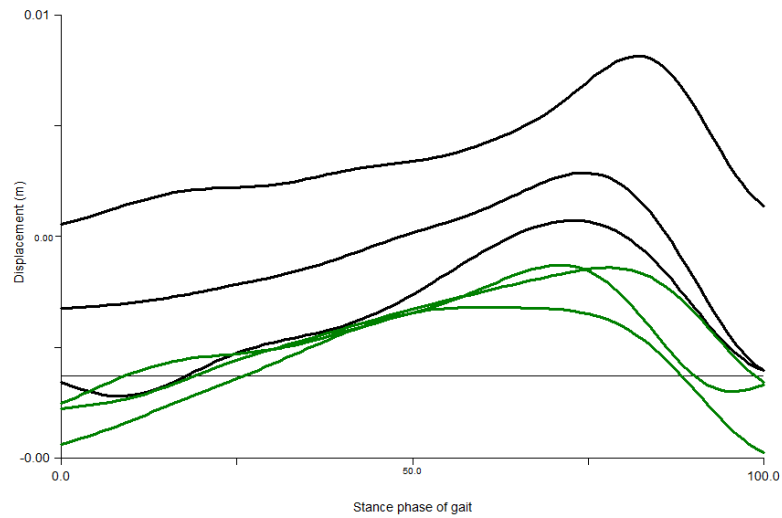


Figure 38: Navicular displacement (x) example graph of 2 participants (3 trials for each) normalised to 100% of the stance phase of gait for PTTD (black) versus control group (green).

The movement observed in the X direction (anterior posterior) is minimal, with the overall mean displacement being 2mm. These figures are similar for both the PTTD group and the control group.

Table 12: Displaying descriptive statistics for dynamic navicular displacement (X) PTTD group.

	Minimum, maximum, range (m) and SD for navicular drop (X) during the stance phase of gait for the PTTD group							
min	-0.00024	0.000223	0.000761	-0.00119	-0.00067	0.000836	-0.00191	-0.00037
max	0.006513	0.005351	0.004305	0.004098	0.004234	0.004298	0.0017	0.002836
range	0.00675	0.005128	0.003544	0.005285	0.004901	0.003462	0.003614	0.003201
SD	0.001695	0.001522	0.000976	0.001642	0.001638	0.000957	0.001186	0.001096

Table 12 Continued.

min	-0.00376	-0.00349	-0.00353	-0.000028	0.000201	0.000116
max	0.007516	0.003643	0.003285	0.004851	0.00479	0.004964
range	0.011279	0.007131	0.00681	0.004879	0.004589	0.004848
SD	0.002044	0.00177	0.001838	0.001097	0.001013	0.001068

Table 13: Displaying descriptive statistics for dynamic navicular displacement (X) for the control group.

Minimum, maximum, range (m) and SD for navicular drop (X) during the stance phase of gait for the control group							
min	-0.00067	-0.00138	-0.00084	-0.00132	-0.00097	-0.00016	-0.00046
max	0.004234	0.002601	0.002827	0.002872	0.003012	0.003258	0.005932
range	0.004901	0.003976	0.003669	0.004192	0.00398	0.003413	0.006395
SD	0.001638	0.001019	0.001154	0.001084	0.001263	0.001131	0.001455

Table 13 continued.

min	-0.00087	-0.00092	-0.00073	-0.00108	-0.00128	0.003443	0.003702
max	0.002963	0.002684	0.002293	0.002773	0.002677	0.008104	0.007506
range	0.003831	0.003608	0.003021	0.003849	0.003961	0.004661	0.003804
SD	0.001311	0.001106	0.00096	0.001242	0.001154	0.001184	0.001056

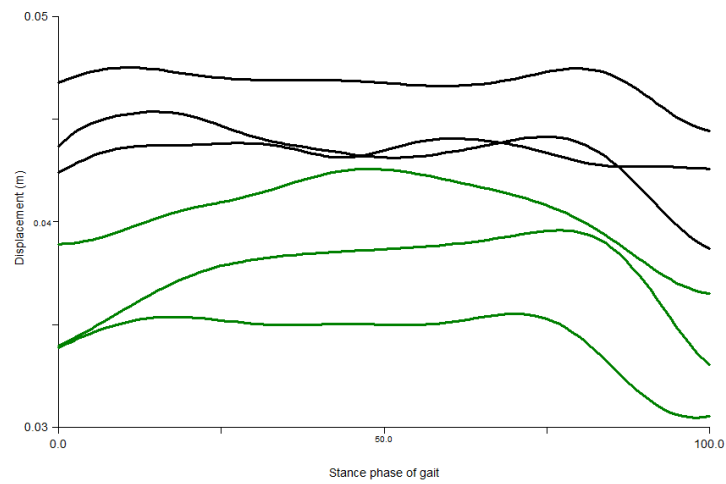


Figure 39: Navicular displacement (Y) example graph of 2 participants (3 trials for each), normalised to 100% of the stance phase of gait for PTTD group (black) and control group (green).

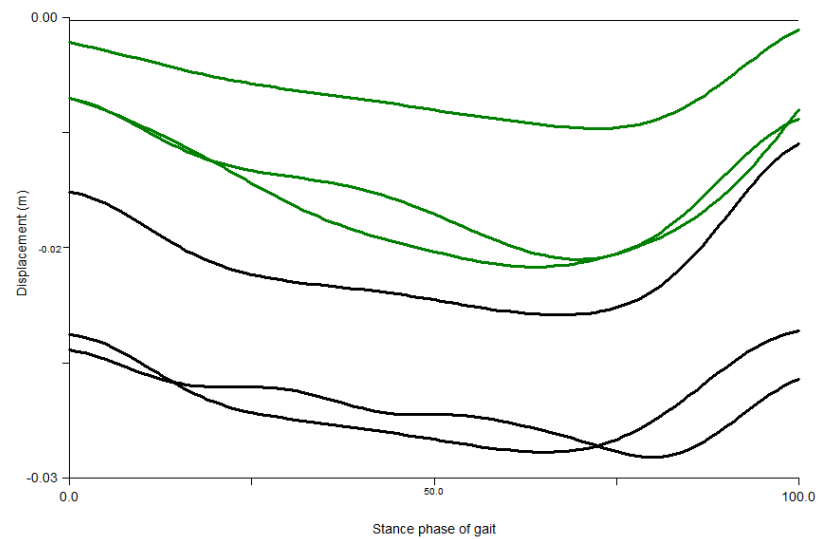


Figure 40: Navicular displacement (Z) example graph of 2 participants (3 trials for each) normalised to 100% of the stance phase of gait for PTTD (black) and the control group (green).

For mediolateral displacement in (Y) measuring NDri, figures reported here are consistent with some of those reported in the literature for the a-symptomatic population. Positive values of NDri indicate that movement of the navicular medially is consistent with convention used in previous studies (Cornwall & McPoil, 1999; Kothari et al., 2014).

For vertical displacement measuring dynamic NDro (Z), the findings presented here provide comparable results, with a mean displacement measure of 7.9mm for the PTTD group and 5.5mm for the control group.

Table 14: Displaying descriptive statistics for dynamic navicular displacement (Y) PTTD group.

	Minimum, maximum, range (m) and SD for navicular drop (Y) during the stance phase of gait for the PTTD group										
max	0.043862	0.042941	0.043582	0.043715	0.046762	0.045066	0.050729	0.052919	0.050652	0.050729	0.047469
min	0.037919	0.03662	0.036988	0.037734	0.040523	0.038555	0.047601	0.048276	0.048106	0.047601	0.04565
range	0.005943	0.006321	0.006594	0.005981	0.006239	0.006511	0.003128	0.004643	0.002546	0.003128	0.001819
SD	0.001568	0.001698	0.001659	0.001529	0.001586	0.00185	0.000686	0.001105	0.000754	0.000692	0.000403

Table 14 continued.

max	0.046762	0.045066	0.050729
min	0.040523	0.038555	0.047601
range	0.006239	0.006511	0.003128
SD	0.001586	0.00185	0.000686

Table 15: Displaying descriptive statistics for dynamic navicular displacement (Y) control group.

	Minimum, maximum, range (m) and SD for navicular drop (Y) during the stance phase of gait for the control group								
Max	0.046762	0.045066	0.050729	0.052919	0.050652	0.050729	0.047469	0.048088	0.048103
Min	0.040523	0.038555	0.047601	0.048276	0.048106	0.047601	0.04565	0.045491	0.046473
Range	0.006239	0.006511	0.003128	0.004643	0.002546	0.003128	0.001819	0.002597	0.00163
SD	0.001586	0.00185	0.000686	0.001105	0.000754	0.000692	0.000403	0.000653	0.000498

Table 15 continued.

Max	0.052516	0.050484	0.048764	0.047701	0.043793
Min	0.04818	0.047853	0.042786	0.041556	0.038848
Range	0.004336	0.002631	0.005978	0.006145	0.004945
SD	0.00115	0.00077	0.001346	0.001627	0.00138

Table16: Displaying descriptive statistics for dynamic navicular displacement (Z) PTTD group.

	Minimum, maximum, range (m) and SD for navicular drop (Z) during the stance phase of gait for the PTTD group										
min	-0.03097	-0.03157	-0.02983	-0.03013	-0.03095	-0.0296	-0.03067	-0.02899	-0.02905	0.042786	0.041556
max	-0.02079	-0.02147	-0.02213	-0.02156	-0.02107	-0.02096	-0.02307	-0.02279	-0.02242	0.048764	0.047701
range	0.010179	0.010103	0.007695	0.008578	0.009881	0.00864	0.007594	0.006196	0.006633	0.005978	0.006145
SD	0.002878	0.003383	0.002515	0.002474	0.003241	0.002719	0.002013	0.001809	0.001608	0.001346	0.001627

Table 16 continued.

min	-0.02735	-0.02664	-0.02562
max	-0.00319	-0.00444	-0.00717
range	0.024159	0.022201	0.01845
SD	0.005585	0.005195	0.00519

Table 17: Displaying descriptive statistics for dynamic navicular displacement (Z) control group.

	Minimum, maximum, range (m) and SD for navicular drop (Z) during the stance phase of gait for the control group										
min	0.038848	0.034988	0.035518	0.035216	0.035761	0.038201	0.037919	0.03662	0.036988	0.037734	0.040523
max	0.043793	0.040298	0.039748	0.040056	0.04077	0.043831	0.043862	0.042941	0.043582	0.043715	0.046762
range	0.004945	0.00531	0.00423	0.00484	0.005009	0.00563	0.005943	0.006321	0.006594	0.005981	0.006239
SD	0.00138	0.001557	0.001264	0.001243	0.001337	0.001693	0.001568	0.001698	0.001659	0.001529	0.001586

Table 17 continued.

min	-0.02321	-0.02272
max	-0.01247	-0.01123
range	0.01074	0.011494
SD	0.002328	0.002963

6.9.8 Heel rise manoeuvre

The statistical analysis for the static heel rise data comparing the PTTD group and the control group demonstrates that for participants with PTTD the maximum heel height achieved during a single heel rise manoeuvre did not differ significantly from that of the control group. Comparing the PTTD and control groups $U= 95.00$, $SE=15.37$, $p=0.67$.

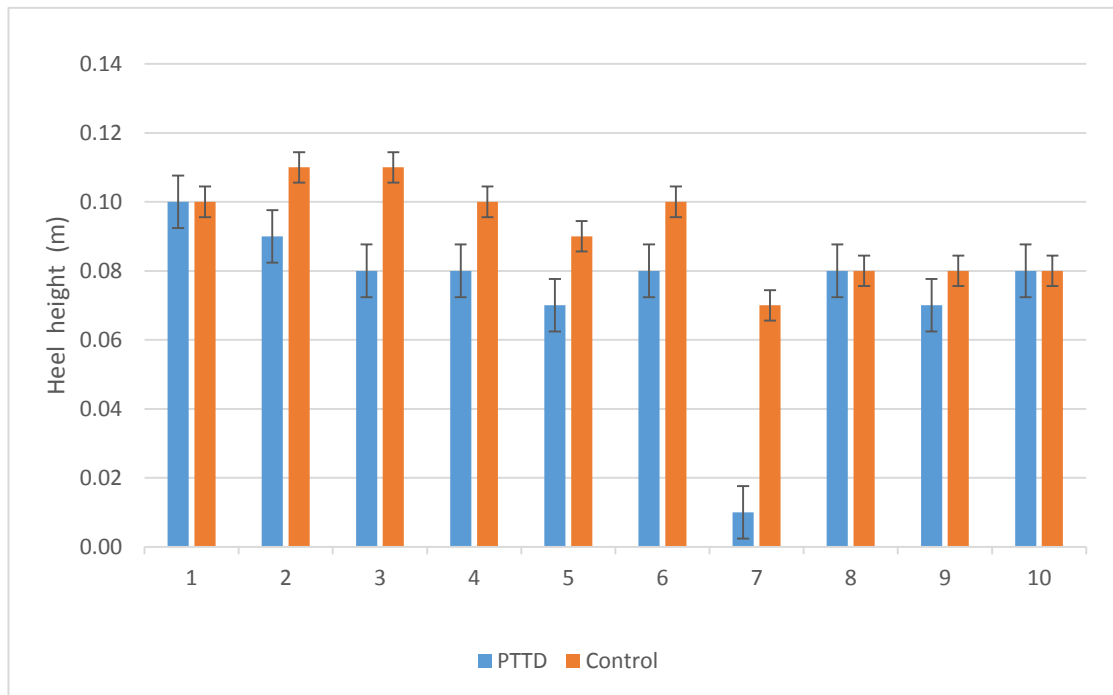


Figure 41: Bar chart illustrating the mean heel heights for the PTTD group and the control group.

The bar graph above provides the mean of 3 trials per participant comparing the PTTD group (blue) with the control group (orange).

Table 18: Displaying static heel height data.

Mean, minimum, maximum, range and standard deviation for static heel rise heights (m)		
	PTTD	Control
min	0.01	0.07
max	0.10	0.11
range	0.09	0.04
mean	0.07	0.09
SD	0.024129	0.013984

The following section illustrates navicular drop and drift (Y and Z) during a single heel rise manoeuvre. The data is presented as mean data for the control group and the PTTD group separately and then as combined graphs. The red line on all graphs represents the maximum heel height achieved during the manoeuvre.

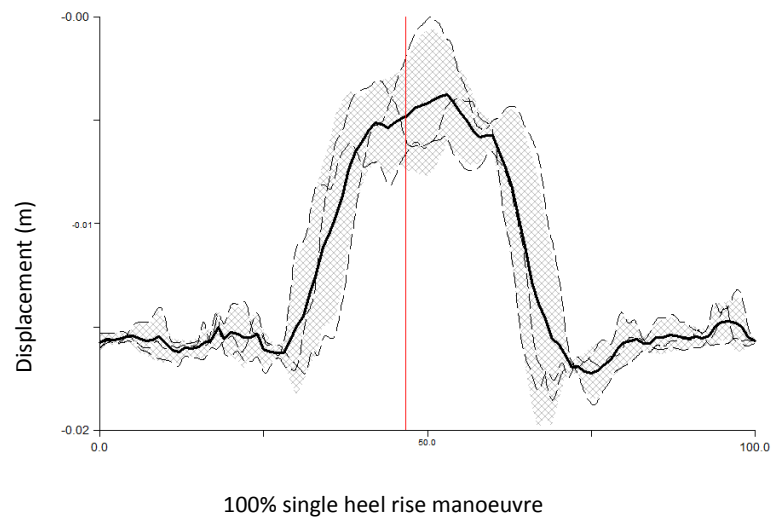


Figure 42: Graph illustrating navicular drop (Z) for the control group during a single heel rise manoeuvre.

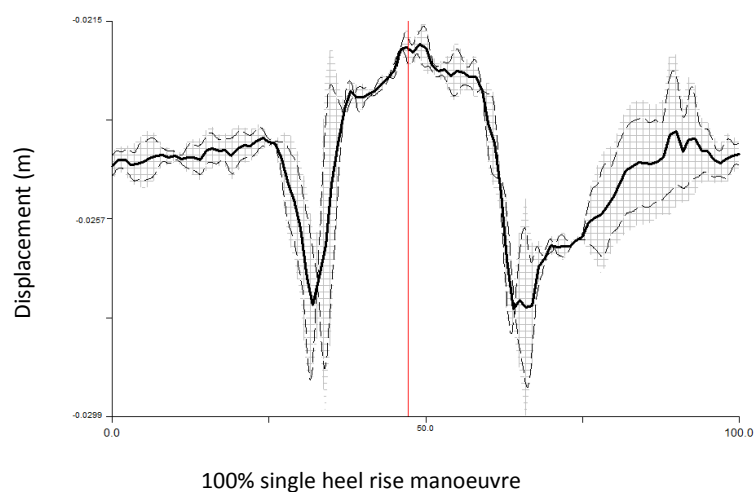


Figure 43: Graph illustrating navicular drop (Z) for the PTTD group during a single heel rise manoeuvre.

Table 19: Displaying descriptive statistics for navicular drop (Z) during a single heel rise manoeuvre.

	Minimum, maximum, range (m) and SD for navicular drop (Z) during a single heel rise manoeuvre for the PTTD group									
Participant	A1		A2	A3			A4		A5	
min	-0.01977	-0.03557	-0.03606	-0.03594	-0.03072	-0.0306	-0.03061	-0.02508	-0.0236	-0.0247
max	-0.00883	-0.02545	-0.02603	-0.02588	-0.02373	-0.02433	-0.02382	-0.01603	-0.01548	-0.01647
range	-0.01094	-0.01013	-0.01003	-0.01006	-0.00699	-0.00626	-0.00679	-0.00904	-0.00812	-0.00824
SD	0.003094	0.002326	0.002292	0.001747	0.001598	0.001538	0.00145	0.002968	0.002325	0.002928

Table 20: Displaying descriptive statistics for navicular drop (Z) during a single heel rise manoeuvre.

	Minimum, maximum, range (m) and SD for navicular drop (Z) during a single heel rise manoeuvre for the control group									
Participant	B1			B2			B3			B4
min	-0.01692	-0.01706	-0.01654	-0.02869	-0.0145	-0.01526	-0.01521	-0.02925	-0.02478	-0.0203
max	-0.00681	-0.00224	-0.00463	-0.02207	-0.00827	-0.00664	-0.0055	-0.02167	-0.00868	-0.01172
range	-0.01011	-0.01482	-0.01191	-0.00661	-0.00624	-0.00862	-0.00971	-0.00758	-0.01611	-0.00858
SD	0.00333	0.004456	0.003918	0.001416	0.001514	0.002811	0.002954	0.001592	0.003668	0.002574

Table 20: Continued.

Participant			B5		
min	-0.0225	-0.00938	-0.00925	-0.00928	-0.01483
max	-0.01031	-0.00321	-0.00272	-0.0022	0.010354
range	-0.01219	-0.00616	-0.00653	-0.00708	-0.02518
SD	0.003439	0.001829	0.00197	0.001905	0.006489

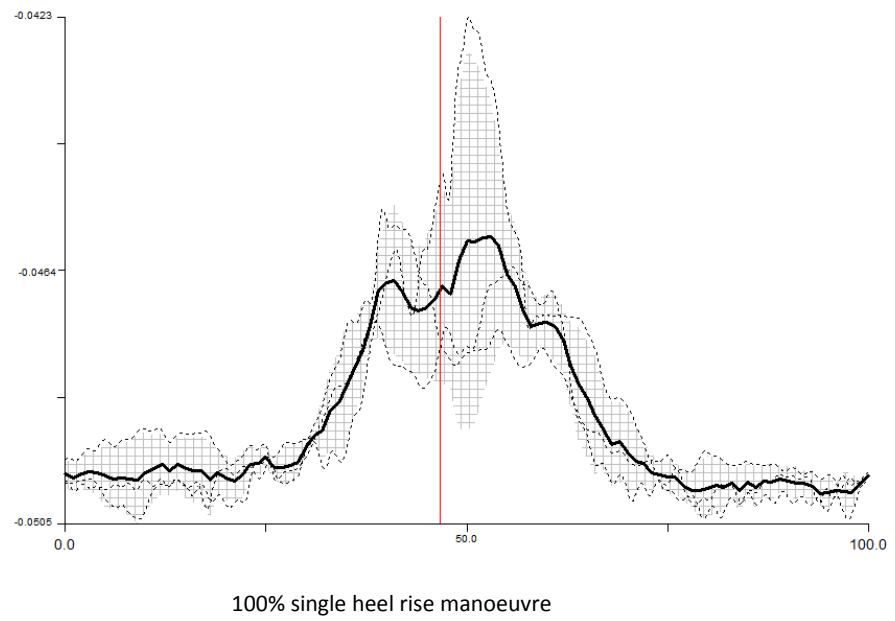


Figure 44: Graph illustrating navicular drift (Y) for the control group during a single heel rise manoeuvre.

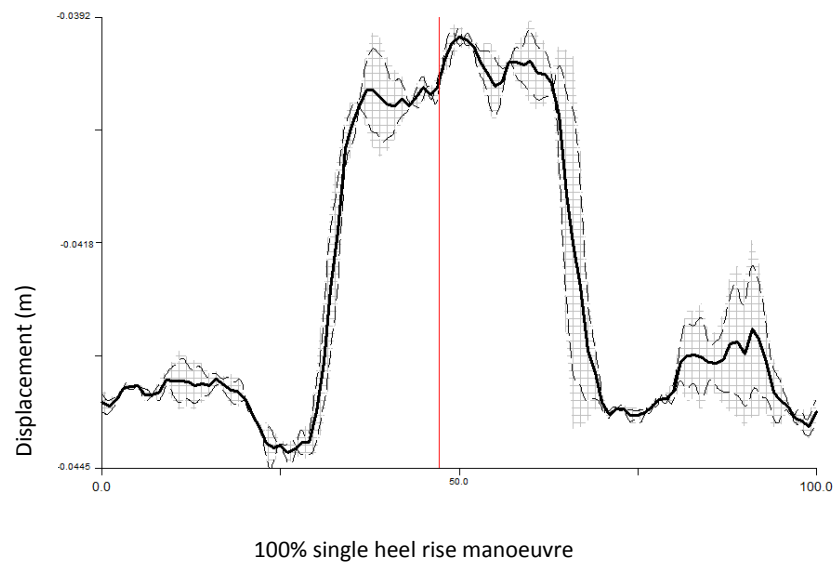


Figure 45: Graph illustrating navicular drift (Y) for the PTTD group during a single heel rise manoeuvre.

Table 21: Displaying descriptive statistics for navicular drift (Y) during a single heel rise manoeuvre

	Minimum, maximum, range (m) and SD for navicular drift (Y) during a single heel rise manoeuvre for the control group.									
Participant	B1			B2			B3			B4
min	-0.04991	-0.05024	-0.05046	-0.03619	-0.03511	-0.03512	-0.03772	-0.04259	-0.04225	-0.04122
max	-0.04732	-0.04241	-0.04564	-0.02948	-0.03045	-0.03009	-0.02967	-0.03809	-0.03547	-0.03565
range	0.002592	0.007823	0.004819	0.006713	0.004667	0.00503	0.008051	0.004507	0.006774	0.005576
SD	0.000773	0.001983	0.001461	0.001776	0.001352	0.001691	0.003274	0.001255	0.002478	0.001623

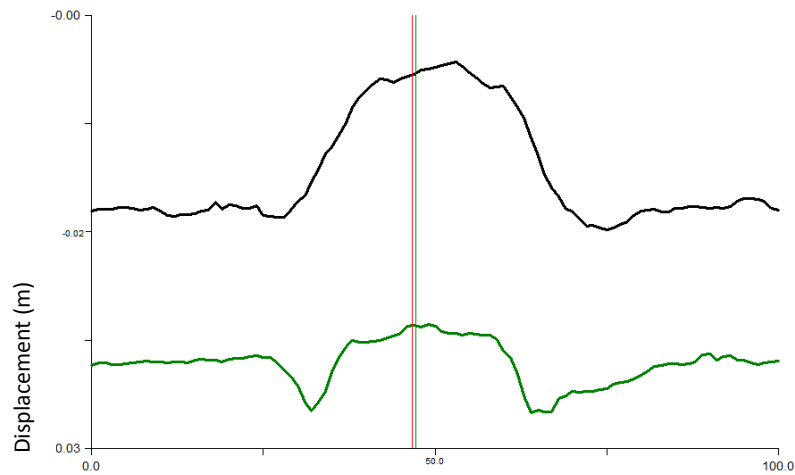
Table 22: Displaying descriptive statistics for navicular drift (Y) during a single heel rise manoeuvre.

	Minimum, maximum, range (m) and SD for navicular drift (Y) during a single heel rise manoeuvre for the PTTD group									
Participant	A1		A2	A3			A4		A5	
min	0.038807	-0.03838	-0.03779	-0.03877	0.048532	0.049001	0.048953	-0.03996	-0.03807	-0.04002
max	0.043728	-0.03279	-0.03358	-0.03333	0.051909	0.051475	0.051518	-0.03309	-0.03283	-0.03252
range	0.004921	0.005594	0.004214	0.00544	0.003377	0.002474	0.002565	0.006872	0.005245	0.007496
SD	0.001876	0.001765	0.001097	0.001321	0.001049	0.000782	0.000893	0.002396	0.001159	0.002717

Table 22 continued.

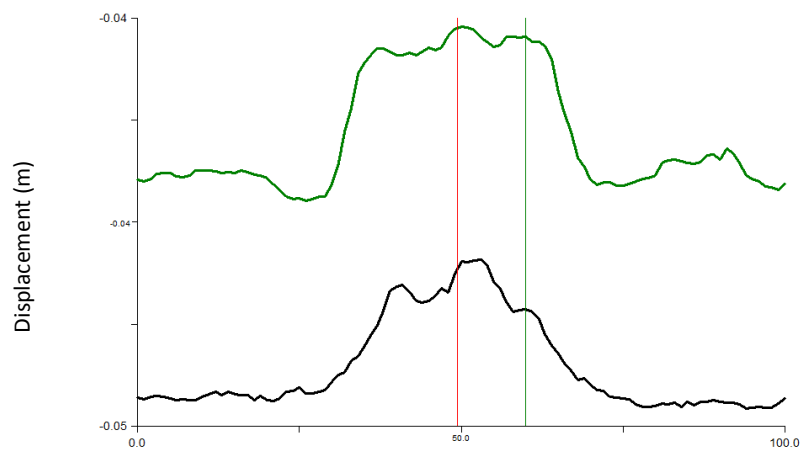
Participant			B5		
min	-0.04151	-0.04151	-0.03816	-0.03938	-0.03923
max	-0.03411	-0.03306	-0.03181	-0.03499	-0.03466
range	0.0074	0.008456	0.006351	0.004388	0.004568
SD	0.002537	0.002575	0.002313	0.001059	0.00142

The red and green vertical lines displayed on the following graph identify when maximum heel height occurs.



100% single heel rise manoeuvre

Figure 46: Graph illustrating mean navicular drop for both PTTD (green) and control groups (black) during a single heel rise manoeuvre.



100% single heel rise manoeuvre

Figure 47: Graph illustrating mean navicular drift (y) for both the PTTD (green) and control groups (black) during a single heel rise manoeuvre.

Statistical analysis for the static heel rise data, comparing the calcaneus relative to the shank (X) during the single heel rise manoeuvre for the PTTD group and the control group, demonstrates that for participants with PTTD the range of valgus angle achieved during a single heel rise manoeuvre differed significantly from that of the control group. Comparing the PTTD and control groups, $U=25.00$, $SE=4.75$, $p=0.008$. The following section displays the data graphically. The green and black vertical line indicated on figures 46, 47, 50 and 51 identify the point where maximum heel height was achieved during the heel rise manoeuvre. Using the right hand rule (figure 21) inversion direction is positive on the graphs and eversion is negative on the graphs.

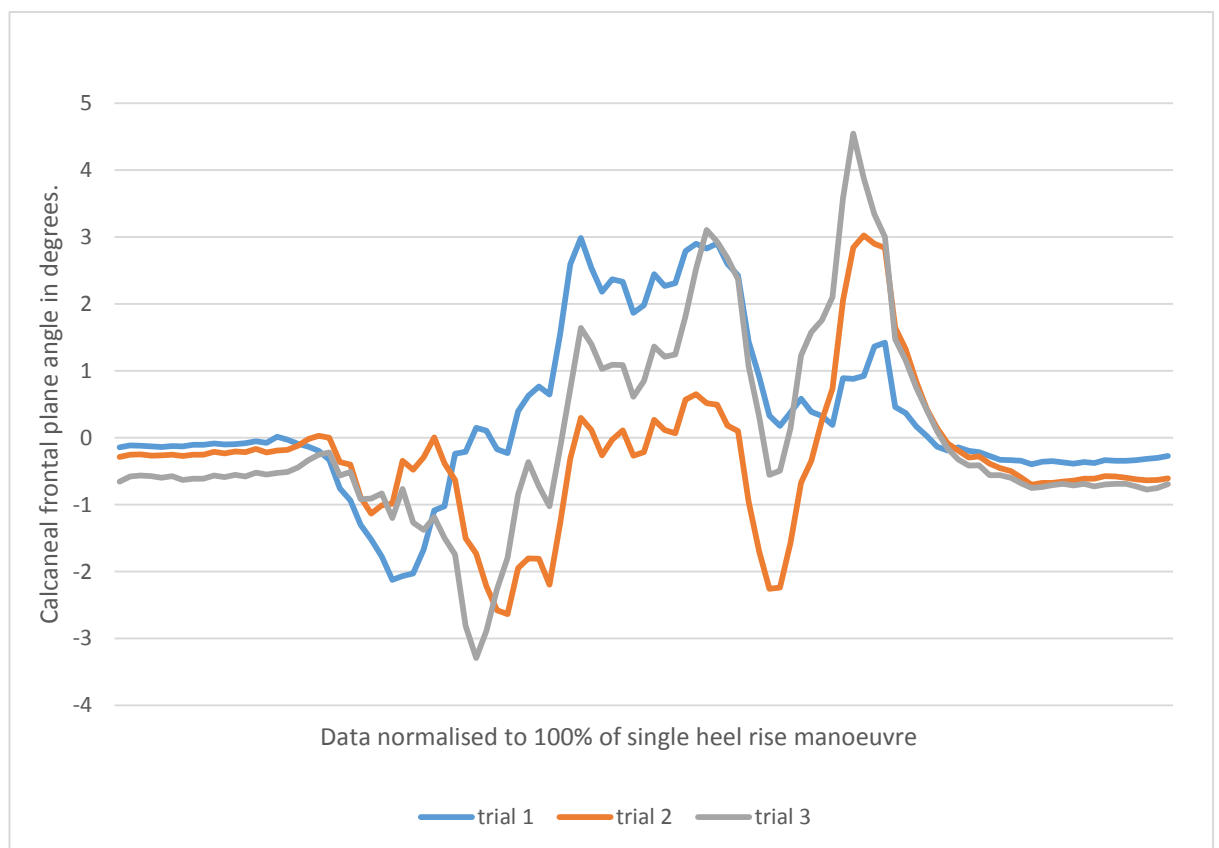


Figure 48: Graph illustrating frontal plane subtalar joint calcaneal angle during a single heel rise manoeuvre.

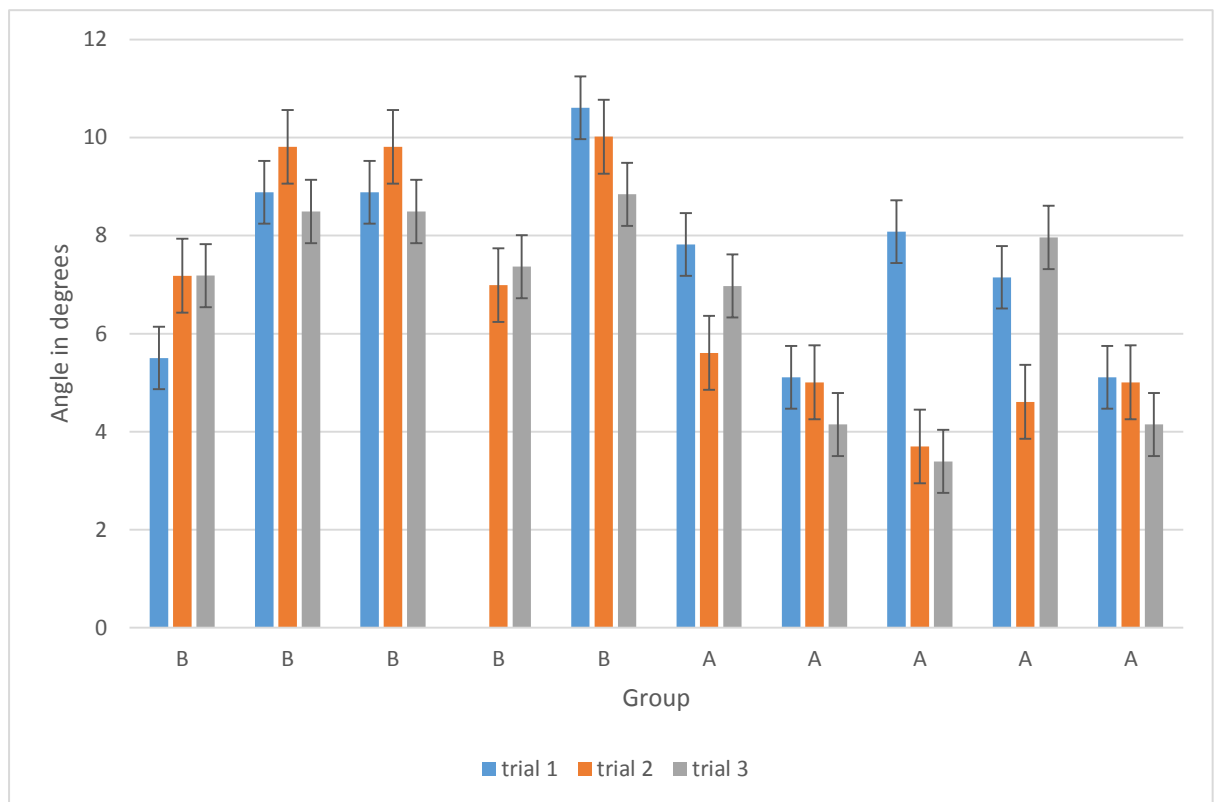


Figure 49: Graph illustrating range of inversion, representing three trials per participant for groups B (control) and A (PTTD).

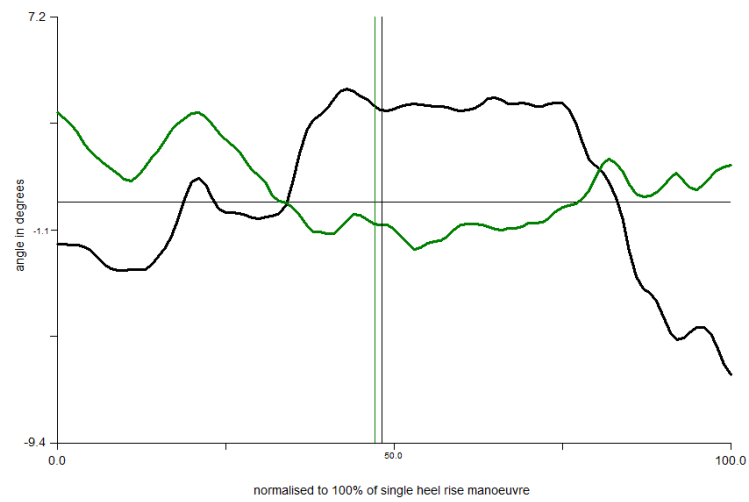


Figure 50: Example graph illustrating the frontal plane calcaneus relative to shank angle for a single heel rise manoeuvre for the PTTD limb (green) and non-pathological limb (black) for the same participant.

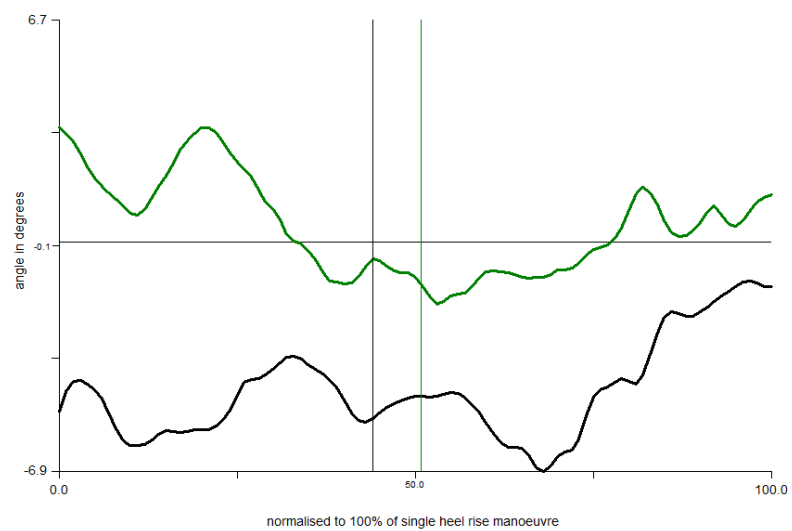


Figure 51: Example graph illustrating the frontal plane calcaneus relative to shank angle for a single heel rise manoeuvre for the PTTD group (green) and the control group (black).

Table 23: Displaying descriptive statistics for calcaneus relative to shank (x) for the PTTD group during a single heel rise manoeuvre.

	Minimum, maximum, range (m) and SD for calcaneus relative to shank angle (X) single heel rise manoeuvre for the PTTD group									
Participant	A1		A2	A3			A4		A5	
min	6.186323	4.485469	2.146933	2.988033	2.100172	2.590717	2.188644	1.419222	-1.35774	-2.16819
max	-1.63334	-1.12236	10.22859	-2.1219	-2.90694	-1.55599	3.697771	3.392823	5.791958	5.794555
range	7.819666	5.607831	8.081652	5.109933	5.007111	4.14671	0.811846	-0.55065	7.149696	7.962742
SD	2.130918	1.181422	1.848521	1.188147	1.321319	0.936406	2.188644	1.419222	1.781062	2.667964

Table 24: Displaying descriptive statistics for calcaneus relative to shank (x) for the control group during a single heel rise manoeuvre.

	Minimum, maximum, range (m) and SD for calcaneus relative to shank angle (X) single heel rise manoeuvre for the control group									
Participant	B1			B2			B3			B4
min	-0.40123	-0.1175	0.192773	-2.9403	1.936823	2.334748	0.490394	2.644908	3.047277	-0.02884
max	10.2041	9.899296	9.035261	-22.8164	-5.0538	-5.03138	-4.52264	-4.28976	-5.57024	-8.91009
range	10.60533	10.0168	8.842488	19.87612	6.99062	7.36613	8.881247	9.81124	8.49124	8.881247
SD	4.01331	3.191993	3.094662	6.164337	1.833073	2.003443	1.541862	1.580859	1.981368	2.398043

Table 24 continued.

Participant			B5		
min	-0.29837	0.618172	-4.59375	0.354193	1.031486
max	-10.1096	-7.87307	0.910544	7.535942	8.214312
range	9.81124	8.49124	5.504295	7.181749	7.182826
SD	2.760434	2.395958	1.791165	1.525782	1.813365

Table 25: Summary table describing NDro and NDri during gait and the single heel rise.

	Stance	SHR
NDri (mm)	4.8* 5**	4* 6**
NDro (mm)	7.9* 6**	8* 10**

*=PTTD group

**= Control group

6.9.9 Foot pressures

The statistical analysis of the foot pressure data produced the results shown in the table below.

Table 26: Results table for statistical analysis of foot pressure data ($p < 0.05$).

Contact Pressure (KPa) Contact Area (cm ²) Peak Contact Pressure (KPa)	TF	MF	M2	M3	M5	T1	T3
PTTD Vs Control Man-Whitney U (test statistic)	96.000	77.000	77.000	106.500	18.000	87.000	73.000
Significance p (0.05)	0.039	0.002	0.002	0.045	0.036	<0.001	0.029
SE	15.875	12.124	12.124	17.317	12.841	1.837	12.841

The statistical analysis of the foot pressure data comparing the PTTD group and the control group for the 13 regions demonstrated that, for participants with PTTD, the contact pressure for the fifth metatarsal, and the first and third toe area were significantly different. Comparing the PTTD and control groups for the fifth metatarsal head area, $U=18.000$, $SE=12.841$, $p=0.036$. For the toe area, T1 $U=87.000$, $SE=1.837$, $p<0.001$, and for T2, $U=73.000$, $SE=12.841$ and $p=0.029$. For contact area, comparing PTTD participants with the control group, the total foot (TF) area, midfoot (MF) and metatarsal head two (M2) area were significantly different. For TF, $U=96.000$, $SE=15.87$ and $p=0.039$. For the MF, $U=77.00$, $SE=12.124$, $p=0.002$. For the M2, $U=77.000$, $SE=12.124$ and $p=0.002$. There was a significant difference between the PTTD and control groups for peak contact pressure at the third metatarsal head', $U=106.500$, $SE=17.317$ and $p=0.045$.

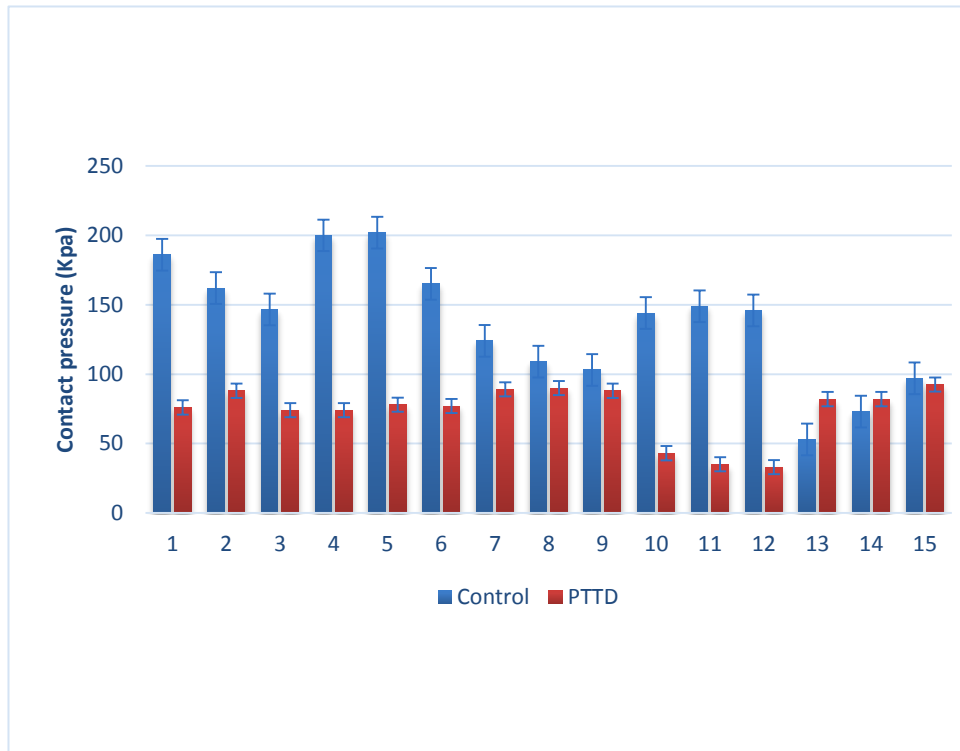


Figure 52: Bar chart illustrating contact pressure for fifth metatarsal head area.

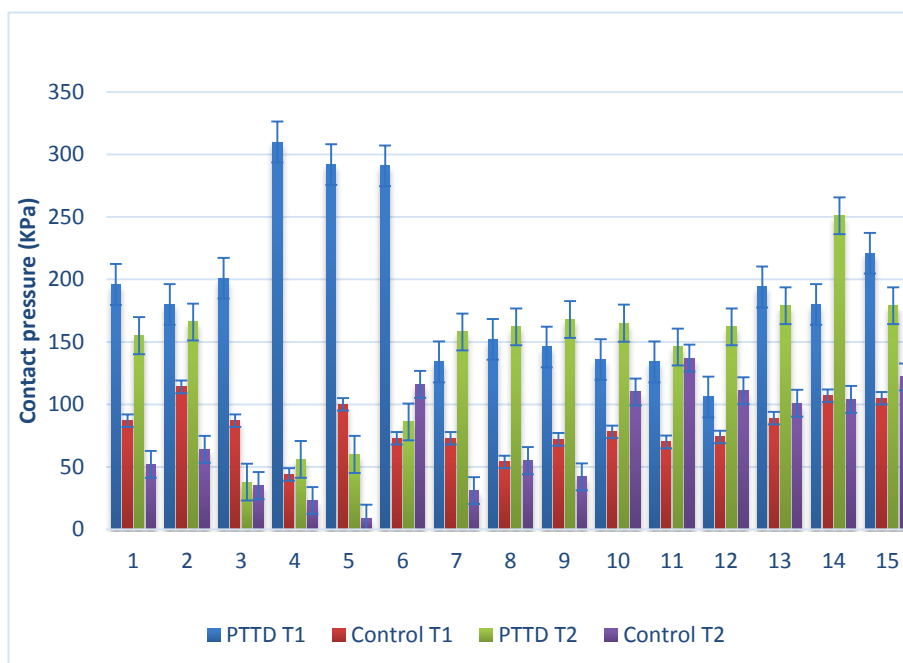


Figure 53: Bar chart illustrating contact pressure for first and second toe area.

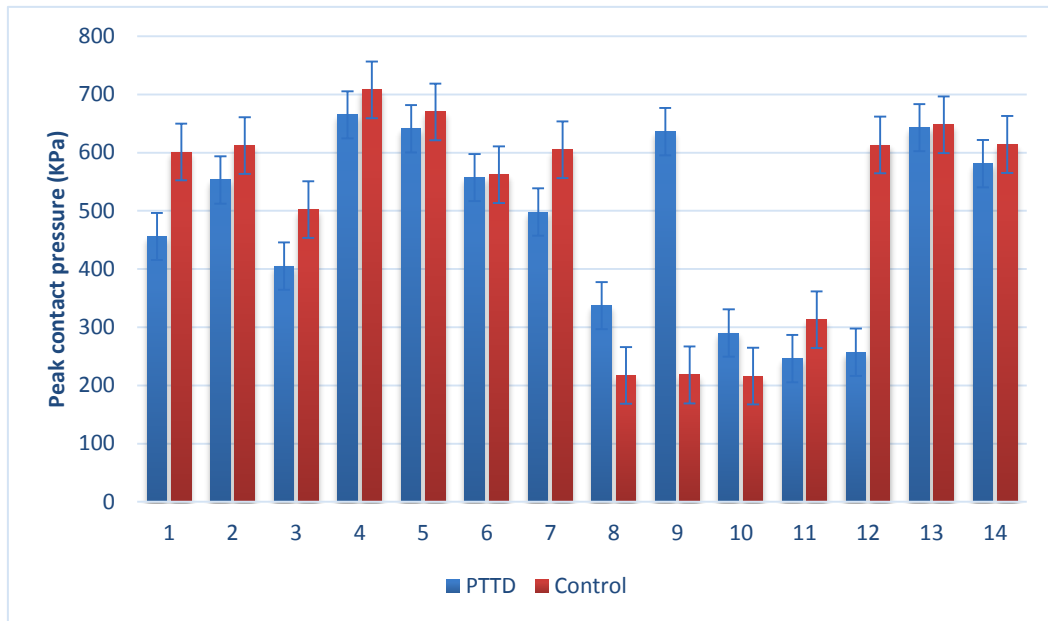


Figure 54: Bar chart illustrating peak contact pressure for third metatarsal head area.

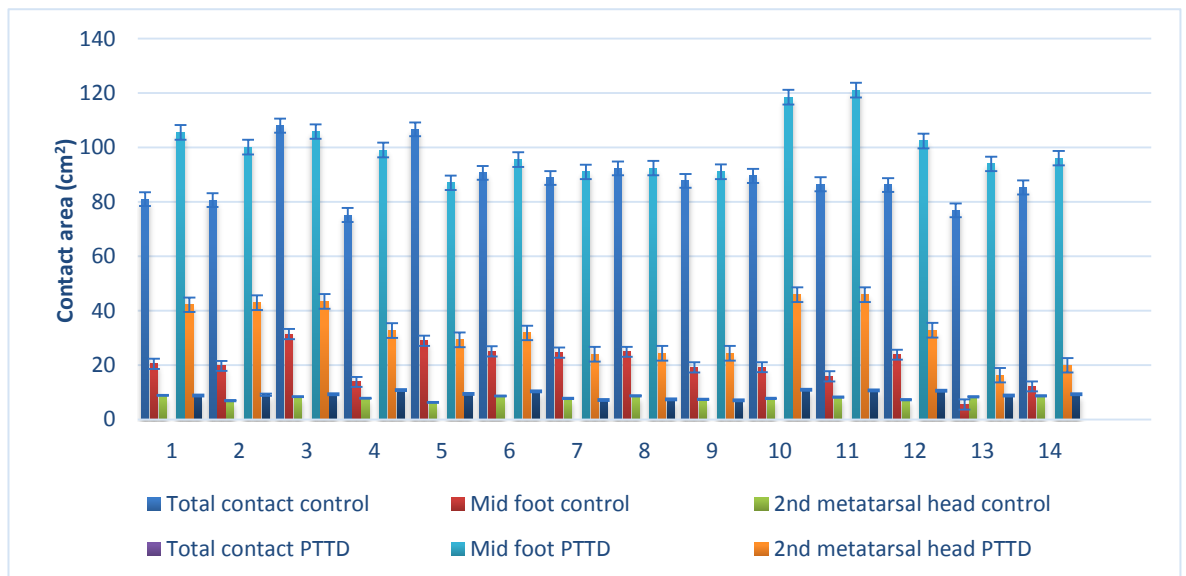


Figure 55: Bar chart illustrating contact area for combined regions.

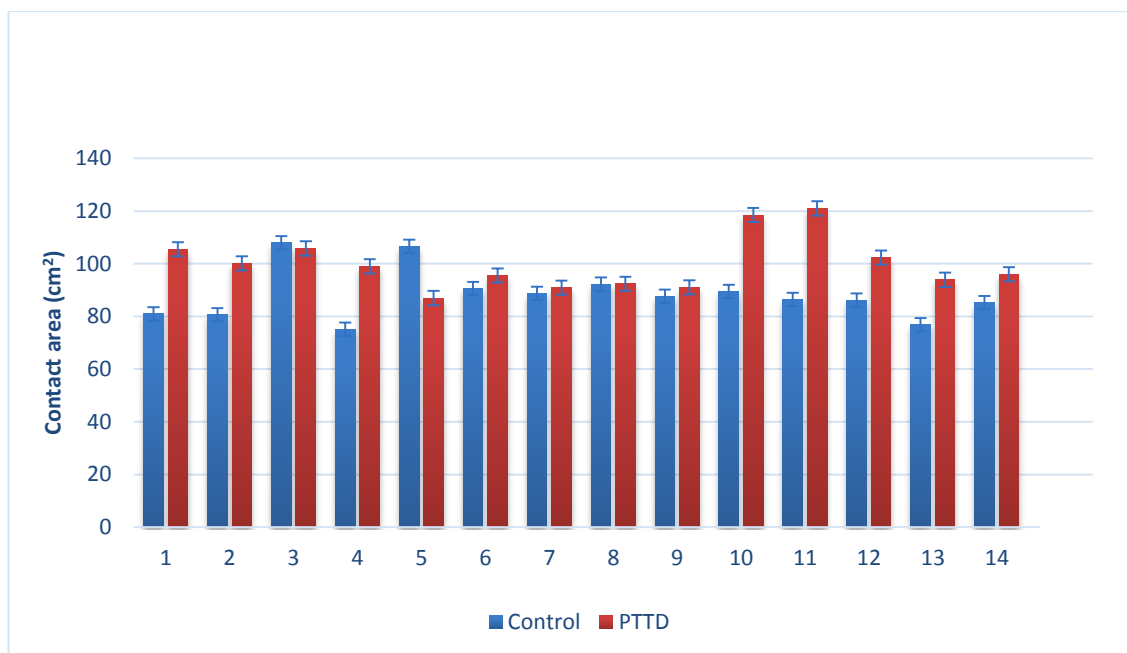


Figure 56: Bar chart illustrating total contact area.

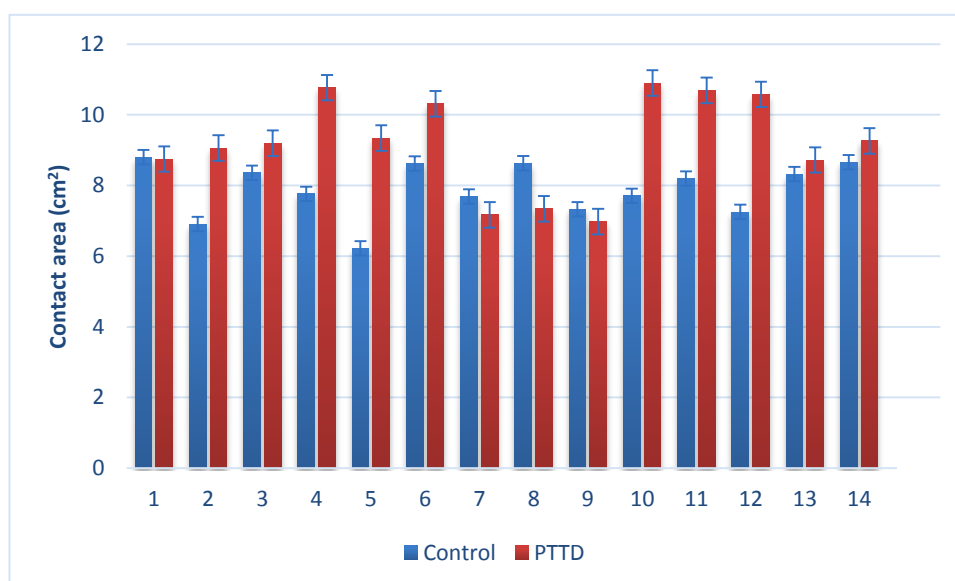


Figure 57: Bar chart illustrating second metatarsal head contact area.

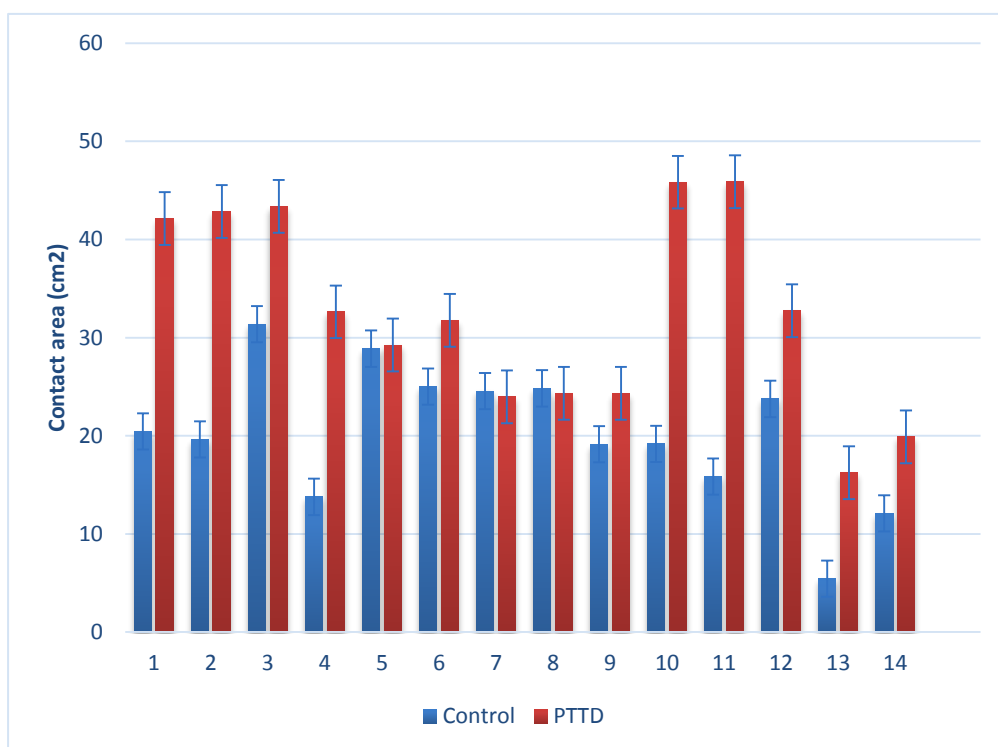


Figure 58: Bar chart illustrating midfoot contact area.

6.10 Discussion

The results presented in this chapter are novel and unexplored in the population described. The discussion covers three distinct areas:

- Static and dynamic navicular displacement exploring NDro (Z) and NDri (Y),
- The single heel rise manoeuvre,
- Multiple step foot pressure assessment.

The data has been presented for two groups of participants, a pathology group (diagnosed with Stage II PTTD by either the MSK podiatrist or an orthopaedic surgeon prior to participating in the study) and a control group.

The discussion will consider each of the three discrete areas of data analysis and will then discuss the links between the data. The results reported in Chapter 4 will be discussed utilising a blended approach.

Navicular displacement was studied during both dynamic gait and a single heel rise manoeuvre. For dynamic gait, the results confirm that there is navicular movement in all three body planes. The movement observed in the X direction (anterior posterior) is minimal, with the overall mean displacement being 2mm. These figures are similar for both the PTTD group and the control group. Anterior-posterior navicular displacement is not well supported in the literature. However, descriptive observation (Cornwall & McPoil, 1999) suggests that movement in this direction is small, which would corroborate the result reported here.

The null hypothesis for this data set presented in this chapter has been accepted suggesting that the NDro, and NDri are similar for both the PTTD and control groups ($p < .05$). However, given the small sample size this is unsurprising. Nevertheless, there are some notable observations, which a larger sample size might exemplify. First, there are differences between the two groups in terms of the relative start position for NDro and NDri. Referring to Section 6.9.7, Figures 38 and 39, where Figures 38 and 39 demonstrate NDri and NDro for both groups; these graphs suggest that the PTTD group demonstrates more drift compared to the control group at the beginning of stance phase.

The study results reported in this chapter reveal that for both groups there was some observable inversion; Figure 47, Section 6.9.8 indicates this, where the positive direction on the Y axis indicates inversion. Statistically, the overall rearfoot calcaneal angle was significantly different ($p=0.008$) between groups (see 6.9.8); Figure 48 indicates an observable difference where there is less inversion than for participants with PTTD. Similarly, Barn et al. (2013) identified a trend toward decreased inversion and increased rearfoot eversion, however the result was not found to be statistically significant.

All the studies quoted here have identified participants in a relatively early stage of pathology. The characteristics that may be demonstrated in a more progressive stage of PTTD are not known.

Furthermore, the results reported on in this chapter have compared the affected foot and unaffected foot and compared the affected foot with a control group. In all instances the results have demonstrated that the calcaneal inversion range is similar across all groups. However, the results show a difference in the inversion start position between groups. The PTTD group displays a relatively more pronated position in quiet standing. Therefore, this suggests that if the maximum excursion angles are similar, then there must be a maximum range of motion that is adopted during the manoeuvre and this may not represent the total excursion of inversion available. This then casts doubt on the concept of rearfoot calcaneal inversion being a factor in identification of PTTD. If a patient has a mobile rearfoot it may be the case that they simply adapt to the relative pronated position of the foot and if there is sufficient available motion the amount of inversion is meaningless.

6.10.1 Navicular displacement

Navicular displacement (NDro and NDri) has been researched and reported in both 'normal' and athletic populations (Cornwall & McPoil, 1999; Kappel et al., 2012; Kothari et al., 2014; McPoil & Cornwall, 1996; McPoil et al., 2013; M. S. Rathleff, Nielsen, Simonsen, Olesen, & Kersting, 2010; Vincenzino et al., 2000; Vinicombe et al., 2001). The significance of the navicular displacement is based upon its relationship to the overall function of the foot. For example, NDro has been associated with a pronated foot type. Static navicular height has been used as a method of determining the amount of pronation in runners. In

1982, Brody proposed a method for evaluation and assessment of static navicular displacement and referred to it as the navicular height test (Brody, 1982) . The resultant displacement has become known as navicular drop.

Brody (1982), related his test results to injury rates in runners, and the test was subsequently used to estimate the amount of pronation in runners. Normal values were reported to be approximately 10mm. However, a number of limitations of this work have since been highlighted; the main shortcoming being the method used to execute the test, and the reliance on a static measure to make inferences about dynamic motion (see Section 2.10 for further detail).

Navicular displacement, and in particular NDro, represents a surrogate measure of foot pronation and rear foot position. Reliability of this measure has been investigated and has received mixed results. Good intra-tester and inter-tester reliability were reported by Sell, Verity, Worrell, Pease and Wigglesworth (1994). The authors of this study investigated two measures, navicular height and calcaneal angle, to assess subtalar joint position.

Measuring three different variables to determine foot position, Weiner-Ogilvie and Rome (1998) found navicular height to demonstrate the best (moderate to good) inter- and intra-tester reliability. Both of these studies are in contrast to the findings of Picciano et al. (1993), who reported poor to moderate intra-tester reliability and poor inter-tester reliability. This study concluded that navicular height was an unreliable measure for the assessment of foot position, and specifically foot pronation.

The three studies cited (Picciano et al., 1993; Sell, Verity, Worrell, Pease, & Wigglesworth, 1994; Weiner-Ogilvie & Rome, 1998) have reported differing results for the static measure of navicular height. Only assessing one component of the overall movement of the navicular may limit the usefulness and reliability of the test, and is one of the criticisms of this earlier work. Additionally, assessing navicular height only reports movement in the sagittal plane.

The manual static test method relies heavily of the clinician executing the test in a reliable and repeatable way. Utilising this method may introduce a multiplicity of errors.

A further study (Vinicombe et al., 2001) explored the reliability of both navicular drift and drop in a 'normal' population, enhancing our understanding of the contribution of navicular displacement to mid foot and rearfoot function. The authors took static measurements of both positions and by doing so reported the mediolateral and vertical displacement. It was concluded that both tests are moderately reliable so should be used with caution given the error associated with inter- and intra-tester reliability. This study reported on static findings using a test that required a reasonable level of experience. Both tests utilised a method similar to that proposed by Brody (Brody, 1982).

Arguably, static assessment has limited value and usefulness in examining foot function. Its application and interpretation for dynamic situations is questionable. A dynamic measure of the height of the navicular would provide more worthwhile information since it would provide a measure relative to walking and therefore a more useful measure of dynamic foot function. Ironically, dynamic measures of navicular displacement were explored over a decade ago. Cornwall and McPoil (1999), reported on dynamic navicular displacement using a three dimensional coordinate system providing directional change in the X, Y and Z directions. This work has provided a fresh insight into the direction and amount of displacement during dynamic movement. Rather than the acceptance of the navicular having measureable movement in the medial-lateral and vertical directions, McPoil and Cornwall (1996) confirmed that observable movement in three dimensions occurs during gait. The anterior-posterior direction demonstrates minimal movement. However, medial-lateral displacement (NDri) demonstrated comparable movement to vertical displacement (Cornwall & McPoil, 1999). Reported values for vertical displacement were similar to those reported by Brody (Brody, 1982), and in conclusion proposed that static navicular height was a good indicator of dynamic navicular movement.

The navicular displacement relationship in PTTD is less well understood. Given the paucity of empirical data to support the use of this test, coupled with the responses given in Chapter 4 by health care professionals (see Sections 4.5, 4.7 and 4.8) which indicate that assessment of the rearfoot and midfoot is important in the diagnosis of PTTD, the results present here are an important step in understanding the contribution this simple test

could make to the assessment of PTTD. This, together with the evidence for navicular displacement being a good indicator of foot posture (Dicharry et al., 2009; McPoil & Cornwall, 1996; Mueller et al., 1993; M. S. Rathleff et al., 2010; Saltzman et al.; Snook, 2001), sets the scene for the discussion which follows.

Literature investigating dynamic navicular displacement, and more importantly navicular displacement in PTTD, is scarce. Kothari et al. (2014) examined navicular displacement in a paediatric population, comparing flat footed children with those with a 'normal' foot posture. Comparison of static and dynamic navicular displacement demonstrated that there were no significant differences, suggesting that both static and dynamic measures yield similar results. The studies to date that have reported on dynamic navicular displacement have studied either a normal or an a-symptomatic population. For such populations an easily executed clinical assessment test has a place in patient assessment.

However, in the case of pathology, it is sensible to look to more sophisticated methods to obtain a more robust interpretation, especially since there is a lack of empirical data supporting the current methods used in pathology. The results presented here are the first of their kind.

6.10.2 Dynamic navicular displacement

For mediolateral displacement in (Y) measuring NDri, figures reported here are consistent with some of those reported in the literature for the a-symptomatic population. Positive values of NDri indicate that movement of the navicular medially is consistent with convention used in previous studies (Cornwall & McPoil, 1999; Kothari et al., 2014).

For this study, the overall mean mediolateral displacement range was 4.8mm for the PTTD group, and 5mm for the control group (see Table 25). The overall measure for dynamic (during gait) navicular drift is similar to that in the published literature. Cornwall and McPoil (1999) reported 4.7mm which is close to the results obtained here. However, much smaller ranges have been reported when assessing dynamic NDri (Kothari et al., 2014), where values reported were significantly smaller with the mean between 1.5 and 2.7mm. Other studies that have given static measures for NDri have provided similar values to the results reported in this chapter. Vinicombe et al. (2001) reported a mean of 7mm and a range of 0-9mm.

A further difference between Kothari et al. (Kothari et al., 2014) was the reporting of negative values for NDri. This suggests that there is some lateral translation of the navicular during the stance phase of gait. This would be expected if the relative start position meant that the navicular was already moving in a positive (pronation) direction at the beginning of the stance phase sequence. However, if this was the case, similar findings would be expected for the results presented in this chapter since the pathology group demonstrated a pronated foot type, and this was not the case.

Another explanation could be that the Kothari study had a different start position. In their study, Kothari et al. (2014) adopted a sit to stand manoeuvre, and found these values to correlate well with dynamic motion. The study results presented in this chapter define all measures relative to the relaxed standing position of the participant.

Given that the majority of studies reporting navicular displacement refer to static measures, this suggests that perhaps the significance of static measures to predict dynamic movement needs to be revisited. Kothari et al. (2014) reported no difference between the static and dynamic values obtained. The fact that the figures for mediolateral displacement were smaller than those reported by other dynamic studies suggests that the method used for obtaining the values was significantly different to that adopted in the other studies.

Rather than interpreting this as meaning that there is no real difference between dynamic and static assessment of NDri, it is possible that the figures are greater due to study design differences, for example, the way in which the baseline values were calculated. Other explanations could include type one errors, although this is unlikely due to the study participant numbers being supported by a power calculation.

For vertical displacement measuring dynamic NDro (Z), the findings presented here provide comparable results, with a mean displacement measure of 7.9mm for the PTTD group and 5.5mm for the control group. These values are slightly lower than the mean values reported by Kothari et al. (2014). Dynamic NDro values for Kothari et al. (2014) were reported to range between 8.9mm and 10.7mm. Dicharry et al. (2009) reported values ranging from 7.9-8.4mm for walking, while Cornwall and McPoil (1999) report 5.9mm.

Although the values are similar to those reported in the literature, the relative start position of the navicular is different to that reported by Kothari et al. (2014). The results here suggest increased vertical drop in PTTD participants compared to the control group, at the beginning of the stance phase. Additionally, the navicular drop values remain in the negative direction throughout the stance phase of gait for the PTTD group. This is juxtaposed to the control group where the values begin from a relatively more positive position compared to the PTTD group, indicating less NDro at the beginning of the stance phase. Although the control group does clearly indicate that NDro is evident, this is less so than in the PTTD group (see Figure 39, Section 6.9.7).

The control group results are similar to those reported by Cornwall and McPoil (1999) in terms of both the pattern and the measure of displacement. Interestingly, the work of Delacerda (1980), investigating 'shin splints' and NDro, reports almost identical figures to the results presented in this chapter. Two groups of participants were selected for the study (Delacerda, 1980), those with a history of shin splints and those without. The group with shin pain demonstrated a pronated foot posture. The authors postulate that the involvement of the posterior tibial tendon function could be partly responsible for the result of their study.

Control participants for the results presented in this chapter demonstrated a neutral foot type while the participants from the PTTD group demonstrated a pronated foot posture. Since this study is the first to report data for dynamic NDro and NDri in participants with PTTD it is not possible to draw from other published studies. However, one similar study by Barn et al. (Barn et al., 2013) examined EMG of the posterior tibial muscle in patients with RA and tibialis posterior tenosynovitis, and provides information on kinematic changes in 'navicular height'. Unfortunately, there is no detail on how the results were obtained and no definition provided for navicular height, therefore comparison of the findings is challenging. Notwithstanding this shortcoming, the results from this study (Barn et al., 2013) provide a fresh look at the activity of the posterior tibial muscle in early tendon disease. Unexpectedly, the results show an increase in the EMG activity of the muscle compared to controls. During walking, increased muscle activity was coupled with a lower navicular height in the pathology group. These results are not directly comparable

to the results presented here, due to the co-morbidities seen in the aforementioned study. Results for NDro described above suggest parallels can be drawn with groups with similar characteristics.

Since the range of NDri and NDro is compared to quiet standing, if the participants in the pathology group were already close to maximum pronation, then the amount of NDri observed during gait may be limited by this fact.

Likewise, if participants in the control group began by demonstrating a position of less drift or drop compared to the pathology group, as indicted by Figures 38 and 39, then the results may not reflect the true amount of NDro and NDri. This point is discussed further, when the other elements of the analysis have been explored. In summary, dynamic NDro and NDri have been shown to be statistically similar for both groups, although the graphical display suggests the baseline comparison and the relative amounts of both NDri and NDro may not reflect the actual range of displacement that would be possible if a different baseline position had been chosen.

6.10.3 The single heel rise test

The single heel rise test was cited in Chapter 4 as a popular assessment method across interdisciplinary teams. Section 4.7.2 presents the responses from both podiatry and physiotherapy professionals, where 37% of podiatrists and 20% of physiotherapists who responded cited the single heel rise test as 'very important' in the assessment of the condition. Amongst the open ended responses there was significant discussion (presented in Section 4.8) that suggests that the way in which this test is conducted and the results interpreted is variable among colleagues. Two of the comments related to this were observations concerning heel inversion and the height of the heel lift. One of the aims of Chapter 6 was to compare heel height and valgus heel angle between the two groups of participants. Additionally, NDro and NDri have been reported for a single heel rise manoeuvre. These three components offer a more comprehensive understanding of the single heel rise test result than has previously been published.

Chimenti et al. (2014) cite the inability to perform the single heel rise test as an important diagnostic indicator for PTTD. This suggests that an inability to perform the test would be

a positive outcome for the diagnosis of PTTD. However, there is scant information to confirm whether the kinematic characteristics of performing a single heel rise test in the presence of are different to those of a non-pathological group.

Furthermore, focussing on the inability to perform the single heel rise test in the presence of PTTD detracts from the need to investigate how the result of a single heel rise test is interpreted. Clinical experience confirms that some patients with confirmed early stage PTTD are able to perform a single heel rise test. This has been further corroborated by the results presented in Chapter 4.

Results from Chimenti et al. (2014), one of a few studies that have researched this test, have shown that in the early stages of the disease there are significant differences in the heel heights achieved during the manoeuvre. The authors recorded a mean heel height of 7cm for the PTTD group compared to 10.6cm for the older age group and 11.8cm for the younger age group. The results presented in this chapter are not dissimilar to those results, with 7cm reported for the PTTD and 9cm reported for the control group.

A further observed characteristic of this test reported by health professionals in Chapter 5 was the amount of heel inversion on rising. In clinical practice this is not measured but rather the heel is observed during the manoeuvre, to detect 'by eye' whether the heel in relation to outcome measures of the single heel rise test itself. Certainly the results in Chapter 4 indicate that this is helpful in assessing PTTD (see Section 4.8 and Appendix 13.3 for further information). Section 2.9.1 discusses the literature surrounding this test in detail. Drawing from studies that have reported kinematic changes in rearfoot motion during the stance phase of gait in PTTD (Josh Tome, Deborah A. Nawoczinski, Adolph Flemister, & Jeff Houck, 2006) , indicates that there is increased rearfoot valgus (eversion) as the foot moves through midstance and propulsion. The question here then, is whether the same may be true for the single heel rise test in the presence of PTTD.

Chimenti et al. (2014) report an overall significant reduction of inversion for participants with PTTD during a single heel rise manoeuvre compared to control participants. However, participants from both control groups in their study (Chimenti et al., 2014)also demonstrated a lack of inversion at peak heel height during the test. This suggests that using heel height as a possible method of interpreting the findings of the heel rise test

may be problematic. Another study by the same group, albeit for a bilateral heel rise manoeuvre (Houck et al., 2009b), reported corroborative findings. During the preparatory phase, participants in the experimental group demonstrated significantly more inversion than the control group. However, at maximum heel height the amounts of inversion were similar for the two groups.

6.10.4 The relationship between kinematic changes in NDri and NDro during the single heel rise test and dynamic NDri and NDro

The relationship between NDro and NDri in patients with PTTD and its relationship to the single heel rise test have never been reported upon. The results presented in this chapter have considered the relative NDro and NDri that takes place during a single heel rise. Previous research discussed earlier in this chapter (see Section 6.10.1) detailed dynamic and static NDro and NDri findings. Chapter 6 reported results for NDri and NDro demonstrating no such association with assessment.

Results from Chapter 4 suggested that the single heel rise test was an important addition to the assessment of PTTD. Interpretation of the outcome of the single heel rise test is not clearly explained within the literature although a number of factors have been proposed (see Section 6.2). Heel height and frontal plane calcaneal inversion are two such factors identified in the findings discussed in Chapter 4. Historically, looking for heel inversion on rising in patients with PTTD has been the mainstay for clinicians executing and interpreting the test. Indeed, in the existing grading criteria for PTTD, observing heel inversion on rising and a diminishing ability to rise onto the ball of the foot are key observations (Abousayed et al., 2015; Bluman et al., 2007; Johnson & Strom, 1989; Myerson, 1996). In some instances a record of whether a patient can perform a single limb heel rise is all that is recorded (Myerson, 1996), whereas for others a recording of whether the patient inverts on rising and can do so with or without pain is a more prominent observation (Raikin et al., 2012).

More recent evidence (Chimenti et al., 2014; Houck et al., 2009b) has reported the kinematic characteristics of this test in both a single and bilateral manoeuvre. Chimenti et al. (2014) detail the results of the performance of a single limb heel rise. Both heel inversion on rising and maximum heel height are presented. In participants with Stage II

PTTD, a significant difference between pathology and older control participants was reported. This represents an alternative outcome measure that does not appear in the currently accepted clinical guidelines.

The results presented in this chapter (see Sections 6.9.2 and 6.9.8) detail maximum heel height and heel inversion comparing PTTD and the control group. The results of this arm of the study are in contrast to those presented by Chimenti et al. (2014), and are more akin to the heel height differences presented for the bilateral heel rise test (Houck et al., 2009b). This could be for a number of study design reasons, not least that the results presented in this chapter represent small group numbers and display a non-normal distribution and have therefore been subject to non-parametric testing. In contrast, the significant results presented within the literature deal with normally distributed data, and have been analysed with more sensitive parametric techniques.

6.10.5 Navicular displacement during a single heel rise manoeuvre

Section 6.9.7 and Figures 42-47 illustrate NDri and NDro during the single heel rise test (drift is positive on the Y axis (mediolateral) and drop is negative on the Z axis (vertical), see Section 6.7.2). The statistical analysis (see Section 6.8.8) demonstrates similar results between the pathology group and the control group with a range of displacement between groups. These results were similar in terms of amount of motion noted, when compared to dynamic NDro and NDri during the stance phase of gait.

The mean range of NDro for PTTD and control participants during a single heel rise was 8mm and 10mm respectively, whereas the mean range for NDri for PTTD and control participants was 4mm and 6mm respectively.

These results are similar to those presented in Section 6.9.7, where dynamic NDro during the stance phase of gait for PTTD and control participants was 7.9mm and 6mm respectively and for NDri for PTTD and control participants was 4.8mm and 5mm respectively (see Table 25).

Although the displacement for NDro and NDri provides similar results for both conditions (stance phase and single heel rise), Figures 41 and 42 reveal some interesting differences regarding the point at which the maximum and minimum values are exhibited, and

provide some context for the point at which maximal heel height occurs during the single heel rise manoeuvre.

For navicular drop (Figure 45), there are distinct differences in the pattern of motion that participants display when compared both to participants with PTTD and with control participants during gait. For the control group, maximum vertical displacement occurs at the beginning of the single heel rise manoeuvre. There is then a decrease in vertical displacement until maximum heel height is reached and then a return to the start position as ankle joint plantarflexion decreases. For the participants with PTTD the pattern of movement is quite different.

At the initiation of the manoeuvre for participants with PTTD, vertical displacement is not at its maximum 'drop' position. As the heel rise manoeuvre begins and the ankle begins to plantar flex there is an increase in NDro which then reaches a maximum as the control participants are moving towards decreasing NDro. This is followed by a plateau when maximum heel height is achieved with a corresponding increase as for the control group. However, as ankle joint plantarflexion begins to decrease, NDro once again increases to match that which occurred on initiation of the manoeuvre. The control group for the same period have returned to the start position of maximum NDro, whereas the PTTD group have a period of recovery where there is a slight decrease in the amount of NDro exhibited (see Figures 42-47).

This is different to the movement patterns during dynamic gait (Figures 38 and 39 in Sections 6.9.7) where there are similar patterns of movement for both groups and where maximum values can be observed at heel strike and toe off. Throughout the stance phase, tibialis posterior is active with two points of increased activity. In normal participants this has been reported to be 3% and 50% of the stance phase (Perry, 1992.), broadly following the expected muscle activity of the posterior tibial muscle. In pathology this is altered, with an earlier contact phase peak and a later terminal stance phase peak (Barn et al., 2013; Basmajian & Stecko, 1963) according to EMG data. Neither of these variables, NDro or muscle activity, coincide with the maximum heel height achieved during gait.

Although the results presented in this chapter have not explored EMG activity of the posterior tibial muscle, from the published work available, it may be that the differences

in NDro patterns are attributable to the changes in posterior tibial muscle activity, and movement patterns appear altered, similar to the way in which muscle activity may be altered. What is unclear, however, is why there is an increase in the amount of NDro exhibited when ankle joint plantar flexion is reducing. This suggests that examination of NDro during the single heel rise test or during dynamic gait may not correlate well with maximum heel height in the single heel rise test, although further work is required to substantiate this.

Turning once again to the calcaneal angle and the shank segment relative to the rearfoot, further anomalies can be found that may help to explain the differences in pattern and the significance of heel height. In the discussion (see Section 6.10.3) observed inversion in both groups was acknowledged and significant statistical differences in inversion were present between groups.

With regard to the calcaneal inversion and the point at which maximum heel height is reached, Figure 48 displays the characteristics for a pathology participant comparing their pathological and non-pathological side. What is clear from this is that the relative start positions are quite different. On the non-pathological side, albeit starting at a more everted position, the rearfoot moved into an inverted position as ankle joint plantarflexion increased and the participant moved onto tip toe.

This position is maintained in inversion but maximum inversion occurs before maximum heel height and begins to decrease and plateau as ankle joint plantarflexion decreases and the participant returns to the start position. Notable is what happens at this end point, where the amount of eversion exhibited is more than at the beginning of the manoeuvre. For the pathological side, the reverse happens. The start position, while in a relatively more inverted position, soon adopts rearfoot calcaneal eversion. Maximum eversion is noted very close to the point at which maximum heel height occurs. This level is maintained with a slight increase in inversion as the ankle plantarflexion angle decreases. However, the foot remains in eversion at the end of the manoeuvre, more so than at the beginning of the event.

The mean results for both groups, PTTD and control group, demonstrate the same characteristics (see Figure 50). Maximum heel height corresponds with maximum

eversion in the pathology group while the same event does not correspond so well with the control group, whereby maximum inversion takes place prior to maximum heel height.

While statistically, the amount of motion was significantly dissimilar between groups, the events and timing of when directional motion occurs are perhaps of equal interest. This is especially pertinent, due to the fact that clinicians are unlikely to measure the angle of inversion, whereas observations of a gait event are easily recorded and can be assessed without the need for complex measurement.

This suggests there is a need for an alternative approach to the interpretation of meaning behind this test. It does appear that, during a single heel rise, significant differences can be seen in the pattern and timing of events. The single heel rise test may not be important in the assessment and diagnosis of PTTD for the reasons once thought. Observation of ability to conduct the test, observations of heel inversion, or the height achieved during the rise may not be the most important factors.

Rather than observing what would be expected in a non-pathological participant, perhaps it is better to acknowledge that participants with PTTD exhibit unique characteristics. One of the areas to consider is the position of the rearfoot on maximum heel height. Rather than looking for a-symmetry with the unaffected side, or observing whether the heel inverts, perhaps we should shift the focus to see if the foot is approaching maximum eversion at maximum heel height. This seems to be a more consistent finding in this group of participants. This is also an easier event to 'spot' as maximum heel height is simply how high the patient can rise their heel from the ground during a single heel rise.

Despite the statistical analysis presented here, exploring NDro during dynamic and static situations reveals no significant differences between the two groups. The graphical illustrations provide further new information identifying patterns in movement not yet explored in the published literature. One of the aims of this chapter was to investigate the relationship between NDri and NDro during stance and during the single heel rise manoeuvre. If NDro is to be used as a measure of foot pronation, as indicated by others (Chimenti et al., 2014; Kothari et al., 2014), it is natural to assume that there may be links

with PTTD since the foot posture exhibited in patients with PTTD is pronated. However, the results here suggest that this may not be the case.

6.10.6 Foot pressures during gait

Foot pressure assessment has been extensively written about especially for gathering normative data (Chuckpaiwong, Nunley, Mall, & Queen, 2008; Deschamps et al., 2015; Franklyn-Miller, Wilson, Bilzon, & McCrory, 2011; Jonely et al., 2011; Queen, Mall, Nunley, & Chuckpaiwong, 2009; S. Rao et al., 2011). In the last decade, foot pressure assessment has been further explored across a wide range of different pathological environments, much of the work focussing on outcome data (Han, Lee, Lee, Lim, & Kim, 2015; Kavros, Van Straaten, Coleman Wood, & Kaufman, 2011; Matheis, Spratley, Hayes, Adelaar, & Wayne, 2014; Periyasamy & Anand, 2013; Queen et al., 2009; Ringleb et al., 2007; Solano, Prieto, Varon, Moreno, & Boulton, 2008).

Despite this, foot pressure assessment has not been extensively explored in PTTD. Limited data is available in the non-surgical arena describing detailed assessment of foot pressures for this patient group (Ringleb et al., 2007). More common is foot pressure assessment representing an outcome tool in post-surgical function, although again in relation to PTTD specifically, the data is limited (Ellis et al., 2010; Matheis et al., 2014).

This section discusses the foot pressure data singularly and then moves on to discuss it further in conjunction with the kinematic results, providing a blended discourse.

The data presented here was collected while simultaneously collecting kinematic data. The kinematic data detailing NDri and NDro showed that these metrics were similar for both groups of participants. The foot pressure data, however, is dissimilar in the categories studied; namely peak contact pressure, contact pressure and contact area.

Participants with PTTD demonstrated increased pressures in a number of regions identified by the application of the auto template which divides the foot into 13 regions for analysis. Of those 13 regions the forefoot and mid foot demonstrated significant differences in peak pressure, contact pressure and contact area. The most notable difference and arguably the region most likely to expect significant differences in PTTD

was the mid foot. Participants with PTTD showed significantly different mid foot contact area and contact pressure characteristics to the control group.

For the midfoot area, the PTTD group demonstrated significant differences ($p=0.002$) where there was an increase in the foot pressures in this region (see Figure 57). The most obvious explanation for this difference would be the expected lowering of the medial longitudinal arch; a common sign in PTTD. However, these results do not tally with two other measures used in the assessment of an abnormally pronated foot. The kinematic changes seen for NDri and NDro did not demonstrate concomitance with the foot pressure results. Since the data was collected simultaneously any changes seen in NDri and NDro would be linked to the profile of the arch. Likewise, if there is a change in the midfoot region, as shown by these results, there would be an expected change in the total contact area of the foot. This was clearly seen statistically ($p=0.039$) and graphically (see Figure 55) for this data set.

Further detail shows changes in foot pressures patterns during the latter stages of the stance phase from heel off through to propulsion, where the PTTD group demonstrated a dissimilar pattern of metatarsal head and toe pressures compared to the control group. At heel off and progressing through to propulsion, the foot would 'normally' be moving through the phasic shift from initial eversion after heel strike and then inversion in preparation for the propulsive phase of gait (Levine, Richards, & Whittle, 2012; Perry, 1992.).

The atypical foot pressure sequence suggests that 'normal' kinetic events were altered for the PTTD group, whereby contact pressure was significantly decreased ($p=0.036$) over metatarsal head five but significantly increased over the first and third toes ($p<0.001$ and 0.029). Peak pressure was significantly dissimilar over metatarsal head three. Referring to Figure 53, an increase in this region for the control compared to the PTTD group is evident. However, this represents peak pressure, and for the contact area over metatarsal head two there is a significant increase for the PTTD group.

These results suggest that the foot may be utilising the forefoot region more medially as the contact area represents the mean contact area during the stance phase between heel

off and toe off. Increases in peak pressure around the third metatarsal head represents the highest pressure value recorded for this region. If the surface area had increased in a corresponding region, as is the case for the PTTD group, this would account for a relatively high peak pressure value, where a higher pressure is recorded because of a smaller surface area. This may mean that the overall contact pressures are a more valuable measure in the interpretation of the results, since if the mean contact pressures have increased alongside contact area, this may have more significance than peak pressure over an unchanged contact area.

There is a paucity of evidence utilising foot pressures either in the assessment or in the diagnosis of PTTD. The results of the questionnaire and focus group discussions presented in Chapter 4 reveal that foot pressure assessment is not in the minds of extended scope practitioners when it comes to assessing PTTD. Analysis of both the questionnaire and focus group data reveals that, with regard to the assessment or diagnosis of PTTD, foot pressure assessment is not considered either between different professional groups or within the same professional group. The mind maps presented in Appendix 12.3 confirm this to be the case. There was no link to assessing foot pressure or using foot pressure measurement as a means of identification of changes associated with PTTD.

The available literature is scant on this topic, with little detail pertaining to discrete areas of the foot (Ringleb et al., 2007). Nevertheless, the limited data available specifically related to foot pressures in PTTD supports the results presented here. Ringleb et al. (2007) found that there was a medial shift in the centre of pressure in participants with PTTD. Like the results here, they also found a non-significant eversion angle during stance when compared with controls (see Section 6.2.4).

In the research exploring foot pressures in the non-PTTD population, some similarities can be found when examining foot posture, and differing foot types. Chuckpaiwong et al. (2008) report on a study exploring foot type on plantar pressure loading, and found that low arch feet demonstrated higher medial contact area compared to a 'normal' foot. Similarly, Sneyers, Lysens, Feys, and Andries (1995) found that overall contact area in the midfoot was lower in the midfoot region for cavoid feet when compared to low arch and 'normal' foot types. However, unlike the results presented here and results reported by

Chuckpaiwong et al. (2008), no link was found between foot type and forefoot loading patterns.

Notwithstanding this, more recently, Kim (2015), investigating foot pressures in flat feet and 'normal' feet while negotiating different terrain, found significant differences in the loading characteristics of the forefoot. Particularly for the flat feet group the second and third metatarsal region was found to have significantly higher contact pressure than a 'normal' foot type. The same author also found significant increases in the mid foot contact area, and this was found to increase at greater walking speed in the flat foot group.

Despite the limited published data examining foot pressures in PTTD, the results reported in this chapter suggest foot pressures should have a more prominent position in the assessment of gait changes in PTTD. Foot pressure assessment may be a more sensitive measure of subtle changes in the loading characteristics in participants with PTTD. As such, including foot pressure analysis in the development of assessment protocols provides a means of differentiation and change detection that other measures, such as navicular displacement and the single heel rise test, do not. Further work is required in this area, however, early indications suggest that foot pressure assessment may have greater sensitivity than more traditional measures.

Making links to these results and those of the kinematic analysis of NDri and NDro, initially seems challenging, since the two set of results are diverse in their findings. However, one explanation is proposed that could account for the lack of significant results in the kinematic analysis and the juxtaposition with the foot pressure results.

Chapter 6 describes how navicular displacement has been used as an indirect measure of foot posture, providing a surrogate measure of foot type characteristics, rather than a direct measure of change in characteristics in the presence of PTTD.

Additionally, participants with PTTD demonstrated a similar range of displacement during gait. This indicates that statistically the range of motion for NDRi and NDro in PTTD and control participants is similar. However, if the range of maximum and minimum movement available is significantly more than is utilised during stance, and is not reflective of actual available motion, this portrays a different focus of analysis. Indeed, for the combined graphical displays, Figures 38 and 39, comparable ranges of motion are evident, albeit the relative start positions are clearly different. This may explain why the amount of displacement in Y (mediolateral) and Z (vertical) is statistically similar but may not explain fully the characteristics seen in participants with PTTD compared to control participants.

While the results have indicated that the motion of navicular displacement is similar in non-PTTD participants in terms of the amount of motion, the pattern of motion is quite different. This suggests that using a different metric to interpret the findings of the test, such as temporal changes in the pattern of movement, could enhance our understanding of how this test could be used to describe changes in foot kinematics associated with PTTD.

Alternative approaches to the analysis aligns more closely with the foot pressure findings. Further work could look at profiling foot pressure characteristics with kinematic changes in navicular displacement, exploring the predictive value in terms of further defining mid foot functional characteristics in PTTD.

Chapter 7: Summative Discussion

The results of the work presented in Chapters 4, 5 and 6 have furthered our understanding of approaches to the assessment and diagnosis of PTTD. Chapter 4 provided results that were unique and unexplored, making a novel contribution to the inter-disciplinary approaches to assessment and diagnosis of PTTD. The study is the first of its kind, exploring PTTD in this manner. The results have highlighted a number of areas where there is a lack of agreement surrounding assessment and diagnosis of PTTD. These fall into three broad areas:

- Resource implications
- Scope of practice
- Clinical awareness

The discussion teases out each of these areas, and broadens the interpretation with content analysis, and then thematic analysis. The outcome of both the key words and phrases, and how these link to the themes identified from the focus group provided a 'map' of key gaps in approaches to assessment and diagnosis of PTTD. These results provided a standalone contribution, adding to the debate surrounding the poor diagnostic profile of patients with PTTD.

Moreover, these results justify the need for the next stage of the study. Chapter 4 highlighted the areas where the most notable disagreement was found. This was illustrated through the closed questionnaire responses, the open ended responses, and the focus group results. Where there was disagreement between all stages of the analysis, a blended approach was taken to explain and discuss the results. Although the results in Chapter 4 are far ranging in topic and application, it has been necessary, due to the constraints and scope of this study, to focus on key areas for further exploration in subsequent chapters.

Chapter 4 revealed that it has become common practice to use some tests in the assessment and diagnosis of PTTD irrespective of the evidence supporting their use. Two of these tests were the single heel rise test and navicular displacement including NDri or NDro. Both of these topics were referred to in Chapter 2 and were carried forward for further exploration in Chapter 6.

Diagnostic imaging was a topic that was highlighted in both the questionnaire responses and the focus group discussions. The reasons given for referral for imaging were wide ranging. This was a dichotomous area where focus group discussions differed from the questionnaire results. Imaging was cited in confirming differential diagnosis, surgical planning, in the identification of other soft tissue structures and in the confirmation of clinical diagnosis for PTTD. The published literature surrounding differential diagnosis and co-morbidities associated with PTTD suggested that plantar ligament dysfunction, and in particular CNL dysfunction, may be one of the missing links in both the onset and progression of PTTD. The current published literature provides a mixed picture regarding the contribution the CNL makes to the assessment and diagnosis of PTTD. In recognition of this, Chapter 5 reports new and novel findings related to this under researched area.

Next, Chapter 6 explores the single heel rise test, navicular displacement and foot pressure assessment. The single test was cited as a popular inclusion in the assessment protocol for PTTD discussed in Chapter 4. The published literature surrounding classification criteria used to assess PTTD refers to this test extensively. However, on critical review of the literature there is no evidence of research surrounding the efficacy of this test when used in the assessment of PTTD. Despite this, for many clinicians, this test is included within the assessment protocol and has an inclusive role in the assessment and diagnosis of PTTD.

Similarly, navicular drop and drift were reported within the context of the content analysis section, although further analysis did not link navicular displacement to the core sampling unit questions. On analysis of the literature, there is an absence of empirical research investigating either NDri or NDro, in a dynamic or static situation in relation to PTTD. Therefore, this test was chosen for inclusion in the study detailed in Chapter 6, exploring the kinematic and kinetic changes of navicular displacement in participants with PTTD compared to control participants. Furthermore, as a novel inclusion, this chapter reported on the relationship between navicular displacement and the single heel rise test.

The results of the discussion in Chapters 4, 5 and 6 have highlighted that some of the key items currently used and referred to in the assessment and diagnosis of PTTD do not provide significantly different results when compared to those for a non-pathological

group of participants. This therefore widens the debate on how assessment protocols are developed and adopted in practice.

What has been discussed thus far has brought new information, aiding an appreciation of the interrelationships between navicular displacement and the single heel rise test. An understanding of the link between these tests and appreciation of how this evidence can be used in clinical protocol development can only enhance the outcomes for patients suffering from PTTD. Furthermore, the blended data analysis surrounding quantitative data acquisition into the clinical assessment of PTTD with the qualitative exploration of the opinions and beliefs of clinicians carrying out the assessment, has provided a unique insight into one of the possible reasons for the poor diagnostic profile of patients with PTTD. Going forward, Chapter 8 provides discussion on how these findings could be incorporated into an evidence based protocol for the assessment and diagnosis of PTTD.

7.1 Limitations

Although this study has highlighted a number of areas that could be used to further advance our understanding of the clinical care of patients with this condition, it is not without limitations and these must be taken into consideration when interpreting the results.

First, the representative groups that were approached to complete the questionnaire do not include GPs. The evidence that is available suggests diagnostic paucity among GPs. The current study targeted registered MSK practitioners as it was felt this would reflect a homogenous group that was likely to encounter this condition on a frequent and regular basis. For this reason, GPs were not recruited to the study, as published data suggests that this group may be more diverse and heterogeneous (Geideman & Johnson, 2000; Holmes & Mann, 1992; Kohls-Gatzoulis et al., 2009; Willing, 2008), and therefore could have changed the focus of the study (Smith, 2009; Willing, 2008).

It could be argued, therefore, that the data do not represent the population that may come into contact with this condition. There are a number of other non-specialist groups that have not been represented. For example, nursing and occupational therapists, both of whom could be the 'first person in' when assessing this condition, particularly in the

older population where community MDT teams are common. Additionally, non-NHS private practitioners were not represented as a group, although many NHS practitioners also work in the private sector.

A further limitation may be the lack of representation of the patients themselves. Certainly anecdotal conversations with patients who have the condition suggest that this group have plenty to say. This is an area that the authors wish to pursue for future research.

The participant numbers in Chapter 6 would ideally have been supported by a power calculation. However, since the topic has not previously been investigated, no baseline or standard deviation could be used to determine minimal effect size. It is hoped that the results of this study will inform future work with regard to sample size.

There were a number of challenges faced by the researcher with regard to recruitment. While this type of problem is not uncommon in clinical research, some of the logistical problems with regard to proximity of the researcher to the data collection site made extension of the data collection time untenable. This reflective narrative will inform the structure and logistics of future work, and as far as is practicable, data will be collected in a laboratory closer to the researcher's academic base.

This study has explored an area that has, to date, not been discussed within the published literature. Over the past decade, increasing levels of research have been published concerning the treatment of PTTD. There is a paucity of research investigating assessment and diagnosis of the condition. This is further hampered by the lack of epidemiological studies in this area. The prevalence of PTTD is such that further research into the assessment and diagnosis of this condition is warranted.

Chapter 8: A pragmatic way forward for clinical protocol development

8.1 Clinical Protocol Development

This study proposed that there is a need for evidence informed clinical protocol development to aid assessment and diagnosis of PTTD. Evidence has shown (Holmes & Mann, 1992) that this condition is poorly diagnosed by health care professionals. The results presented thus far have exposed the need to improve the current *modus operandi* for the assessment of PTTD. Not only is there a paucity of evidence underpinning the content of the current classification documents and guidelines used in the assessment of PTTD, but much of the content of such protocols is based on assumptions that the results presented here have confirmed to be unfounded.

The results from Chapter 4 suggest that there is agreement that an assessment criteria/framework is essential, with 80% of respondents confirming that they strongly agreed. However, the same respondents demonstrated that there was little agreement concerning the assessment and diagnostic techniques currently applied in practice.

There is a reliance in practice on a handful of guidance documents for assessment (Abousayed et al., 2015; Bluman et al., 2007; Johnson & Strom, 1989; Myerson, 1996; Raikin et al., 2012). Chapter 2 summarises the assessment and staging criteria currently in used in clinical practice and the evidence supporting the criteria.

From this it can be seen that there is little other than expert opinion and anecdotal clinical evidence supporting the inclusion of a variety of assessment tests. Despite this, these criteria have been adopted in clinical practice and many clinicians use them as guidelines and do not question the rigor surrounding their development.

The available publications detailing the assessment and diagnosis of PTTD, tend to focus on staging the pathology. That is to say, the tool is used to describe the clinical signs and symptoms associated with progression of the pathology, hence defining stages of progression.

A review of the evidence referred to above, shows that the focus of the content changes, as shown in the title of each publication. Despite all referring to the original classification proposed by Johnson (1983); Johnson and Strom (1989), who focus on tendon

dysfunction, Myerson (1996) considers treatment of dysfunction of the posterior tibial tendon. The refined classification proposed by Bluman et al. (2007) focuses on posterior tibial tendon rupture, while the novel classification proposed by Raikin et al. (2012) looks at systematic approaches to acquired adult flat foot.

The detail surrounding these classifications has been discussed in Chapter 2. They are revisited here in the context of their influence on clinicians who use them to enhance and support the assessment and diagnosis of PTTD. Despite being relied on in clinical practice and cited as a source of reference for diagnosis of PTTD (see Section 4.5) there is little noteworthy empirical data that underpins their use. For nearly thirty years the aforementioned have been accepted in practice, with little question as to their validity. Until recently (Abousayed et al., 2015), the reliability and repeatability of the clinical tests referred to within these publications have gone unchallenged.

The work presented here has suggested that there is a lack of clarity surrounding items that should be included in the assessment of PTTD. This perhaps stems from a scarcity of published material dealing with the development of assessment criteria in foot pathology, and an absence of material for specific pathologies such as PTTD.

Jarvis and co-workers (Jarvis, Nester, Jones, Williams, & Bowden, 2012) conducted a two part study investigating, firstly, the identification of biomechanical assessment protocols used in clinical practice. The study utilised a Delphi technique for the initial stage of defining the criteria and the tests that would constitute a biomechanical assessment. This was followed by inter-tester reliability of a subset of the content of the protocols identified in part one. The results showed that the selection of tests chosen by clinicians to form part of their foot assessment gave inconsistent and unreliable results. The authors found that participants selected static weight bearing techniques based on the 'Rootian' model of assessment. The study concluded that, given that the aim of clinical assessment is to decipher normal from pathological, the results of the investigation suggested that it would not be possible to accurately classify either. Using the selected tests to differentiate normal from pathological would not be considered valid clinical practice.

Interpretation of the results from selected tests can often provide misleading results if the tests are not specific to pathology. Different foot postures have been shown to display different kinetic and kinematic characteristics. Foot measures employed in the kinematic assessment of foot pathology have been shown to be significantly different between foot types (Hillstrom et al., 2013). Participants with differing foot types, who presented with no pathology were investigated. The results show that several foot measures, including medial arch height index, malleolar valgus index, and foot pressure detailing contact pressure, peak pressure, and contact area, were significantly different between foot types in a normal population (Hillstrom et al., 2013; Kim, 2015; Periyasamy & Anand, 2013; Sneyers et al., 1995). This has been discussed in Chapter 6 and related to the results for dynamic kinematic changes.

If both loading characteristics and assessment findings arising from common clinical tests differ in different foot types, then coupled with the fact that there is a lack of agreement on which tests should constitute the assessment in the first place, this suggests that the current *modus operandi* is questionable. Chapters 4 and 5 and 6 highlighted that an assessment protocol needs a combination of:

- Measurable outcomes assessing foot function
- Observable outcomes assessing foot structure
- Clinical experience
- An understanding of the purpose of carrying out the assessment test in the first place

From the findings of the above studies, a lack of association between the purpose of the assessment and its link to assessment of pathology is evident. Chapter 4 has investigated the opinions and beliefs surrounding the assessment and diagnosis of PTTD. Despite being presented with a specific pathology to relate the assessment approaches to, there was widespread disagreement as to what was important and necessary in order to provide a timely diagnosis (see Sections 4.7-4.9 in Chapter 4). The open ended responses provided a plethora of different approaches to assessment. The lack of consistency was evident throughout both the questionnaire and the focus group responses.

Part of the problem perhaps lies with a lack of understanding about whether a test is diagnostic or whether it simply helps to build a clinical picture of foot structure and function. The assessment of foot structure is arguably more straightforward than that of foot function. Assessments of foot structure can easily be carried out in a clinical setting with little equipment. An example would be the use of the FPI, a validated tool for the assessment of foot posture, based on observation of various foot structures. Foot structure evaluation requires little equipment when compared to that of foot function, where equipment for measuring foot pressure and kinematic assessment require not only specialist kit but also specialist knowledge.

Mootanah et al. (2013) investigated whether static measures of foot structure, such as the valgus index and the arch height index, could predict foot function. Foot function was assessed using temporal and spatial parameters of gait. Regression models were used to predict the ability of the structural measures to predict function. In all cases the regression analysis was significant. This suggests that structural foot measures can be used in the prediction of foot function. The authors postulate that if foot function is related to foot structure, then these more easily executed tests could be used to assist with differential diagnosis of foot pathology. Additionally, the authors suggest that treatment planning and treatment efficacy could benefit from the outcomes of this research. Given that foot pathology is associated with malalignment, deformity or damage to soft tissue structures, all of which could attract costly assessment techniques, the results of this study offer a less costly and more feasible clinical application.

Although foot structure might predict foot function, this does not mean that it will help to diagnose foot pathology. Mootanah et al. (2013) and Hillstrom et al. (2013) conducted their trials on healthy participants. So while foot structure might predict function, these results refer to a non-pathological homogenous group.

The debate surrounding the development of clinical guidelines is not straightforward. They are developed with improvements to the quality of patient care in mind. Some suggest that clinical guidelines form the key foundations for quality improvement

(Abdelhamid, Howe, Stokes, Qureshi, & Steel, 2014), although the impact that they have on clinical practice, especially on primary care, is variable (Steel et al., 2014).

A recent study (Abdelhamid et al., 2014) investigated the use of clinical guidelines in primary care and found that, although widely available in primary care, many were not based on applicable research. The study followed a mixed methods Delphi approach and analysed the views of GPs scoring of 14 commonly used guidelines. The results showed that GPs' views on whether they would follow a guideline were variable. The likelihood of not using a particular guideline increased when they realised that the evidence supporting its development was not based in the population that they were likely to encounter, for example, primary care patient populations.

Many clinical guidelines currently in use are based on evidence for interventions, and as such have undergone significant review of that evidence during their development. The National Institute for Health and Clinical Excellence (NICE) have invested significant resources in producing evidence informed clinical guidelines for use in all areas of the NHS including primary and secondary care. The clinical guidelines produced by NICE are said to be among the best there are (Scullard, Abdelhamid, Steel, & Qureshi, 2011), and are essential reading for anyone involved in patient care. The validity of clinical guidelines is dependent on the evidence and data available and chosen for inclusion (Steel et al., 2014), with NICE guidelines using the best available evidence at the time of development (NICE, 2014).

There are few clinical guidelines for assessment of musculoskeletal care, and this is particularly so for specific conditions such as PTTD. Although guidelines can be developed for areas other than interventions and treatment, this is not commonly seen in practice. Unsurprisingly, priority is likely to be given to conditions that are major causes of morbidity and mortality in a given population, or where there is emerging evidence that health care processes could improve outcomes in care, or where evidence suggests uncertainty in the appropriateness of aspects of patient care. Given these criteria, guidelines are commonly produced for areas where there is epidemiological evidence to

support development, or where there is evidence that can be assessed, such as the evidence surrounding interventions improving the outcomes for patient care. For conditions such as PTTD, there is a paucity of epidemiological evidence, limited to just a handful of studies (Holmes & Mann, 1992; Kohls-Gatzoulis et al., 2009a; Thomas et al., 2011).

The results presented within this body of work are the first of their kind exploring the views of specialist practitioners about assessment and diagnosis of PTTD. In recent years there have been a number of publications concerning the timely intervention of this condition (Houck et al., 2009a, 2009b; Houck et al., 2008; Neville et al., 2009, 2010, 2013; Neville et al., 2007; J. Tome, D. Nawoczinski, et al., 2006), with little evidence to support assessment, aside from the work of this thesis (Durrant et al., 2016) and a recent publication (Abousayed et al., 2015) which was critical of the dearth of validity in the existing clinical guidelines surrounding assessment, diagnosis and the staging of PTTD.

Only one clinical guideline has been developed following the process outlined above. Published for treatment of Stage II PTTD (Bowring & Chockalingam, 2009), it highlights the complexities of developing clinical guidelines. This study used a modified Delphi approach to gain consensus on items for inclusion. Although this is a welcome addition to a sparsely populated area of the literature, issues remain surrounding the usefulness of a clinical guideline for treatment that included tests that have little or no empirical data supporting the items included. For example, Bowring and Chockalingam (2009) discuss the controversial single heel rise test and what role it plays in the management of PTTD. Moreover the authors acknowledge the work by Yeap et al. (Yeap et al., 2001), who challenged the sensitivity and specificity of this test as a diagnostic indicator. The results in Chapter 6, Sections 6.9.2 and 6.9.8 have also highlighted some of the difficulties in the interpretation of this test. However, because consensus was gained within the group participating in the Delphi study, this item was included in the final guideline in the assessment section. The consensus group was comprised of appropriate members, likely to be involved in the conservative care of patients diagnosed with PTTD, and the guideline was written with the identified patient population. Therefore, despite addressing the

issues outlined by (Abdelhamid et al., 2014; Shekelle, Woolf, Eccles, & Grimshaw, 1999), difficulty remains in some areas, where the test has been used in clinical practice historically, but is lacking in evidence to support its use. In these circumstances challenging the status quo is essential in order to influence and generate clearer clinical protocols to enhance patient care.

The results from Chapter 4 demonstrate that there is a willingness to embrace the use of assessment and staging criteria to aid improvement in the diagnostic profile of the condition. However, also apparent (see Chapter 4, Sections 4.7.1.-4.7.8) was the obvious concern surrounding the ability of the 'first person in' to be able to recognise the signs and symptoms of the condition. Moreover, there was a lack of confidence that inexperienced clinicians would be able to successfully manage the condition.

In one quote, "wide spread ignorance" was the term used to describe current understanding of the condition in general practice. Some comments refer to a lack of acceptance that PTTD is a debilitating condition in its own right with one participant saying:

"... I think there's a widespread ignorance about this condition [pause] so a lot of people won't know much about it. There needs to be a dissemination of information that this is a true pathological condition that needs to be recognised, it needs to be diagnosed early, and I think that's probably a really important thing from this ..." (Foot and ankle surgeon).

Congruently, discussed in Chapter 4, over 90% of respondents agreed that the diagnosis of PTTD could be improved and yet there was widespread disagreement about some basic but potentially fundamental questions that could influence a timely diagnosis and subsequent management. For example, there was a lack of agreement between different health care professionals surrounding the time it takes currently to obtain a diagnosis. There was a lack of agreement on whether imaging was required to confirm the diagnosis and a lack of agreement as to how the condition progresses and whether symptoms would improve without intervention. Conversely there was agreement that the quality of life of patients with PTTD is adversely affected.

Given that all of the respondents to the questionnaire were in extended scope practice roles, working solely within the musculoskeletal field, these results are concerning.

Moving on, the open ended responses reported in Chapter 4 suggested that while there was support and a keenness to have clinical guidelines and criteria to assist assessment and diagnosis, some of the highly cited words and phrases describing various key elements of observations and tests referred to in the assessment of PTTD also demonstrated discord. There was a general level of uncertainty about which tests and observations should be incorporated into such a guideline or assessment criteria. For example, the single heel rise test was frequently cited as an item for inclusion in the assessment of PTTD and yet the results in Chapter 6 demonstrate that, in assessing the merits of the test comparing a pathology group with a control group, the results were mixed (see Section 6.9.3). Likewise, navicular drift, drop and sag, were all mentioned in the key word content analysis and were frequently cited words (see Sections 4.7.4- 4.7.8, and 4.8), however the inclusion of this test and the interpretation of the results have never been assessed in this patient group. The results in Chapter 6 suggest that the interpretation and focus of the results of this test may need to shift. Assessment of displacement per se was not seen to be effective in differentiating pathology participants from the control participants. However, assessing 'patterns' of motion in relation to the temporal and spatial parameters of gait could be an alternative approach to interpreting the results (see Sections 6.2.1-6.2.3).

It is commonly recommended as an integral method for the development of clinical guidelines, to adopt consensus methods such as Delphi type approaches, or mixed methods approaches utilising questionnaire and focus groups. NICE guidance (NICE, 2014) says that members involved in the production and development of clinical guidelines must make collective decisions about the need to review protocols, interpret the evidence and, in order to make recommendation, they need to reach consensus. This process is also recommended in other publications discussing this topic (Abdelhamid et al., 2014; Scullard et al., 2011; Shekelle et al., 1999; Steel et al., 2014). What precedes this process, and is recommended in the majority of the guidance, is a review of all the available evidence. Developing clinical protocols, may involve referring to and reviewing

existing clinical guidelines, or designing new ones. This is especially important where contradictory evidence exists, or where, on reviewing the literature, no evidence exists.

Clinical protocol development goes further than the use of clinical guidelines. The NHS Institute for Innovation and Improvement provide a comprehensive guide for developing local clinical protocols. The table on page 199 highlights 12 steps involved in that process. Included within this is a review of the literature and existing guidelines and protocols.

Clinical protocol development is more far reaching than clinical guideline development because it encompasses all personnel who may be affected by the protocol. With assessment and diagnosis of PTTD in mind, clinical protocol development would address more of the issues that have been raised from this work. For example, the themes identified within the focus group and discussed in Chapter 4, would be addressed by a clinical protocol. Resources, scope of practice and clinical awareness of the condition would all be addressed within the 12 step approach to setting up the protocol. Resources would have to be addressed in steps 1, 4 and 6. Scope of practice would be addressed in steps 2, 3 and 5. Clinical awareness would be addressed in steps 3 and 5.

Table 27: Steps towards clinical protocol development (adapted from <http://www.institute.nhs.uk>).

Step	Descriptor	Explanation
1	Select and prioritise a topic that is important for your service	This can be achieved through reviewing guidelines and protocols that are currently in use. Or identification of a service improvement that is not covered by any existing guidelines.
2	Set up a multidisciplinary service	This will include clinical and non-clinical staff likely to be affected by the protocol.
3	Involve patient, service users and carers	This is to ensure that everyone affected by the protocol's use is involved in the development.
4	Agree objectives that are specific, measurable and have targets for achievement	
5	Build awareness and commitment within the organisation	High levels of support are needed for the implementation of a new protocol.
6	Gather information to inform the protocol development.	NICE guidelines, other clinical guidelines, reviews of the literature surrounding the topic.
7	Perform a baseline assessment	This helps to confirm and define the current position.
8	Produce the protocol	A simple document that guides staff through the process.
9	Pilot the protocol	Address operational problems, make any necessary amendments.
10	Implement the protocol	The aim would be for the protocol to become an integrated part of everyday practice.
11	Monitor variation	Monitor what actually happens in practice and whether this varies from the protocol.
12	Review	To ensure that the protocol remains current, up to date, effective and continues to help maintain high standards of clinical care.

8.2 Implications for clinical management

Protocol based care attempts to standardise what happens to patients, where, when and by whom. It formulates a framework for multidisciplinary working, helps to raise awareness of standards of care, and sets about streamlining care to reduce variation in practices. Developing a clinical protocol for PTTD would enhance care for patients. It would bring together the evidence that is available in the conservative and surgical management of the condition. This would sit within clinical guidelines for each, which would be embedded within the protocol.

The body of work presented here has highlighted the need for more empirical evidence of the efficacy of some of the tests and observations currently employed in the assessment of PTTD. The lack of clarity and agreement surrounding what the assessment of PTTD should include could be addressed by utilising the recommended clinical protocol development guidelines. Inter and intra-rater reliability alongside sensitivity and specificity testing would form part of the protocol development exploiting similar methods to those outlined by Jarvis et al. (2012), and it could be further developed following a similar method to Bowring and Chockalingam (2009).

At the heart of both clinical protocol and guideline development is the desire to improve patient care. PTTD is a debilitating foot condition and more needs to be done to address the poor diagnostic profile associated with this condition.

Chapter 9: Conclusion

9.1 Concluding Remarks

If the clinical practice gap between evidenced successful conservative management and reported poor diagnostic capability is to be bridged, new guidance and educational training surrounding PTTD should be produced, with the non-specialist in mind, as well as with up-skilling for the existing extended scope clinicians.

This study has provided robust investigation into the opinions and beliefs of health care providers through questionnaire and focus group discussion concerning the assessment and diagnosis of PTTD. The results have demonstrated that there is a lack of agreement both within and between groups of health care clinicians who commonly encounter this condition, highlighting what may have been suspected previously but which has never been investigated or reported.

Having a robust clinical framework to enable clinicians to grade the progression of the pathology is dependent on being able to recognise the pathology in the first place. The results of this study have provided evidence to confirm that diagnosis of this condition by health care professionals is poor. This has been substantiated with the results in chapter 4, where a plethora of differences in the approach to assessment has been observed. This suggests that, despite the existence of clinical classification guidelines designed to aid assessment and treatment, a paucity of assessment and diagnostic certainty continues to hinder progress in this area.

Some tests currently employed in the assessment and diagnosis of PTTD are woefully under researched. The inclusion of a clinical test in an assessment protocol must be both justified and evidence based. Historical practice based on expert opinion alone is insufficient justification. Tests such as the single heel rise and navicular displacement have questionable significance in assessment and subsequent diagnosis of PTTD. The results in Chapter 6 have shown that when comparing test results with a non-pathological population, the results are equivocal. This in turn, challenges the efficacious application of these tests in practice. Furthermore, qualitative results in Chapter 4 demonstrate a lack of agreement about the approaches to assessment and diagnosis of PTTD.

Chapter 6 has demonstrated that some measures of function, such as kinematic displacement of the navicular, are similar for both participants with PTTD and non-pathological controls. Likewise, some measures of foot function, such as rearfoot calcaneal angle in the single heel rise test, have been found to be dissimilar for the participant groups. Moreover, interpretation of the results of the classical single heel rise test is inconsistently reported and Chapter 6 has demonstrated different results when compared to the suggested findings for an early stage presentation (Stage II according to Johnson and Strom (1989)). Until further research is conducted in heterogeneous populations, predictive models may not be helpful in improving detection of foot pathology.

Furthermore, other kinematic characteristics may be beneficial in understanding the changes associated with progression of PTTD. Inclusion of dynamic navicular kinematics has illustrated some interesting findings in terms of temporal and spatial differences, despite navicular displacement (NDri and NDro) demonstrating similar results to a non-pathological group. This level of specificity is not currently reflected in the classification and assessment tools that are available.

The results presented in this body of work have demonstrated that there is a lack of consistency in the approach taken to assessment and diagnosis of PTTD. Appropriate and best care may be dependent on the scope of practice and experience of the clinical teams. This suggests that guidance should be provided to non-specialist health care groups who may be the first to come into contact with this condition. Further collaborative working may also enhance the long term prospects of patients with this disabling and under recognised condition.

In conclusion, this thesis has provided an exciting, original contribution to the understanding of PTTD. Further work has been proposed in Chapter 10, and the results contained herein have provided a spring board towards achieving these aspirational future proposals.

Chapter 10: Recommendations for future work

10.1 Future Directions

This study has highlighted a number of areas for future work. These are summarised as follows.

1. As a result of the disagreement which is evident in the findings presented in this thesis, further work is required in order to gain agreement over the items to be included in the assessment of PTTD, for example, clinical tests. This could take the form of a Delphi study that could be used to develop a clinical protocol.
2. The inclusion of any test in an assessment protocol should reflect evidence informed decision making and be in accordance with recognised guidelines. Further work is required with a larger, powered sample size, to gain an understanding of sensitivity and specificity of clinical tests in the detection of PTTD.
3. Further work is required concerning the contribution that other soft tissue structures, such as the CNL, have on the progression of PTTD. A sub-section of future study in this area should include further work surrounding soft tissue imaging and the presence of other soft tissue pathology that may be present at the time of diagnosis, so that these structures can be factored into any subsequent intervention and management.
4. Further training is required for both extended scope clinicians and non-specialist clinicians who may be in a position to make onward referrals for assessment and diagnosis of PTTD.
5. Patients and the wider public have not been consulted throughout this study. In order to address this shortcoming, two Patient and Public Involvement (PPI) studies are currently underway. This work will precipitate any further post-doctoral studies that emerge from this thesis. These two studies will explore the patient 'journey' from onset of symptoms to the point of diagnosis and from the point of diagnosis throughout their treatment and management.

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Appendices

12.1 Example of open ended responses with key words highlighted.

1

5. In your experience, what do you consider to be the classical patient reported symptoms for PTTD? Text Response

shin splint like pain tip toe pain
 pain and swelling of ankle heel pain on standing
 Pain on inside of ankle
 Medial ankle pain, aching, tiredness, swelling, lateral foot pain, inability to single heel raise, overweight, female,
 middle aged lady, increase in activity levels/work, footwear issues
 medial ankle pain/swelling/inflammation ankle weakness
 Pain on mobility Foot deformity Specific location of pain
 medial ankle often with proximal medial arch pain weakness of foot on walking
 Unilateral pain worse standing along and behind medial malleolus
 Medial ankle pain Collapsed medial arch Pain on palpation on pt Weak pt resisted test Unable to tip toe
 Pain behind the medial malleolus - uni-lateral and no reported injury as such. Maybe noticed or someone else noticed that one foot looks flatter than the other.
 Mild gradual symptoms over a few years or months with aching to start with but then quickly progresses significant change in their activities/ unable to walk as far, walking slowly Unable to lift the heels without being pain free - making them limp Pain along the inside of the foot/posterior medial malleolus, really sore, getting worse Usually an underlying concern of flat feet through life swelling around the posterior medial malleolus
 Pain, change in arch shape,
 pain, gait changes
 Acute searing pain immediately during or after the event Insidious change in foot shape Inability to walk up stairs
 Progressive painful flat foot deformity. Pain around the medial malleolus.
 See my answer to a similar Q above.
 Constant pain when standing and walking on the inside of the foot/ankle which gets worse the longer they are on it and noted flattening of the foot.
 pain in the arch of the foot
 pain and swelling to the medial aspect of the ankle, worse as day proceeds when walking / weight-bearing.
 Pain and swelling on the inside of the ankle.
 medial ankle pain following minor trauma foot collapse
 pain at the back of the ankle. Usually insidious onset. lowering of arch gradual. Unable to walk the distances that could before.
 pain
 Pain in the medial longitudinal arch
 Pain is the most classic symptom in my experience
 heel and plantar midfoot pain shin pain reduced function
 Activity related pain posterior to the medial malleolus

Podiatry responses

The majority of patients I have seen with PTTD have abnormal foot pronation but are asymptomatic. A reasonable number present with additional medial ankle pain, typically along the course of the PT tendon and some present with medial shin splints. A percentage also suffer with lateral interosseous compression pain

relatively sudden onset of pain, swelling, loss of power, deformity - collapse of arch

progressively flattening foot pain, initially medially then as the condition progresses lateral ankle compression reported in addition, dysfunction, difficulty with activity

Pain plantar, dorsal midfoot, medial/lateral ankle pain impacting on mobility as pain on any WB activity, that is progressively deteriorating.

Foot has gradually become flatter/changed compared to other foot. Can't wear any shoes with heels due to pain. Painful whenever weightbearing particularly during increased exertion.

Patients complain of a flat foot often painful which is preventing them from doing their job/sport in the normal manner.

Pain with activity. Foot flattening/rolling in. Post static dyskinesia. Instability and weakness, swelling and pain.

My foot's gone flat and I've got pain up the inside of my ankle.

It is fairly progressed when they start reporting vague medial ankle pain, usually quite pronounced when pain is felt along the tendon. Often they will come in with chronic foot strain or tired feet etc.

Increasing pain and gradual deterioration of function. Sometimes no problem perceived until close to end stage rupture. Soem because relative reports odd appearance.

pain with increased/prolonged activity, change of foot shape, heat/pain/swelling in PTT location, pain, inability to walk, falling.

progressing unilateral flat foot, pain - tib post tendon area (distal or proximal to ankle), inability to continue at current activity levels.

postero medial ankle pain, heel / arch pain, swelling, reduced exercise / work ability, foot changes (flat foot), instability / balance issues.

5. In your experience, what do you consider to be the classical patient reported symptoms for PTTD? Text Response

Aching of sharp pain post medial malleolus to arch of radiating prox 30cm, worse am, walking, Heel raise. Better with support of medial arch

As previous question. Also patients can report sudden onset of pain which may indicate a partial tear. Mostly patients have a long history and sought previous help which has been unsuccessful
athletes, runners, dancers

clicking

Depends on area of specialism. I work in gym rehabilitation, so often secondary following fracture

Female Possibly Overweight Over 40

insidious onset of pain to the medial foot/ankle, may have come on after excessive weight bearing or a sudden increase in running (either distance or time) - change in terrain. Pain is made worse with weight bearing, may have some swelling to the tendon.

med ankle pain, esp after walking, on feel ++time etc. Collapsed med arch Planta F etc

Medial ankle and arch pain exacerbated by standing > walking, and particularly in bare feet or poorly supportive footwear.

Swelling may also be reported

Medial ankle pain, with onset of swelling, pain on loading, walking, may report lateral ankle pain if develop sub fibula impingement

Medial ankle pain/arch pain during walking, worse in unsupported footwear +/- noticed flat foot

Medial ankle Pain difficulty walking Unable to take part in normal activity eg sport

Medial ankle pain Loss of heel raise power Change of foot posture (or abnormal wearing on shoes) Swelling usually later stages)

medial apin with increased loading

Medial foot and ankle pain (excluding the stage 3 and 4 presentations).

Medial foot and ankle pain. Difficulty walking. Insidious onset in middle aged women, sometimes linked to increase in weight, decrease in activity or minor trauma

middle aged woman with progressive weakness in her ankle and tendency to over pronate with associated pain.

nothing at all deformity pain

overweight, late middle age or early old age, inactive, poor general strength

Pain

pain

pain, deformity, problems with shoes.

pain, lack of power during running activities

pain, reduced function

Pain and swelling posterior to the medial malleolus.

pain located at navicular tubercle, medial ankle, or distal tibia. Worse with activity running or walking. Worse after sitting for a while. A.m stiffness.

pain medial aspect with increasing deformity

Pain on impact sport

Pain on standing. Collapsed mid foot/arch.

Pain on the medial aspect of the ankle

Pain on walking which particularly gets worse with distance and often better initially in the day. Patient notices dropping of the arch

PHYSIOTHERAPY RESPONSES

pain on wb (and area)
 pain on weight bearing, particularly when wearing unsupportive footwear (e.g. flip flops)
 pain posterior or inferior to the medial malleolus or navicular. Feeling of weakness. Possible ache at rest after activity
 Pain posterior to medial malleolus
 Pain to posterior ankle joint, and occasionally around the great toe Difficulty running / going up stairs / altered walking pattern due to reduced push off of great toe Ache into the medial arch.
 Pain Weakness Lack of function e.g. push off/heel raise
 pain with activity, push off, dorsiflexion stretch with Hallux extension tender on palpation med aspect of TA length EMS/stiffness after activity
 postero-medial or arch pain. Pain on prolonged weight-bearing. Morning stiffness/pain
 Posteromedial ankle pain
 posteromedial ankle pain - foot pain reduced walking distance mechanical/mechanical-inflammatory picture
 Previous ankle trauma Pain medial ankle Swelling Reduced walking distance/sport limitations if active
 progressive discomfort medial arch, or sometimes top of the foot with increased to training routine, or change of the shoes
 Inability to raise heel up without pain Swelling medial side of the ankle Sometimes discomfort round the muscle of the muscle
 Refer to previous answer re. findings in subjective assessment
 Someone who might be slightly overweight, that is not very active and has poor lower limb biomechanics and poor level of fitness and lower limb strength. They often have diabetes.
 SUDDEN EXACERBATION OF PAIN IN MEDIAL ASPECT OF FOOT ASSOCIATED WITH CHANGE IN FOOT SHAPE
 swelling, pain superior to med malleolus or under navicular, low grade constant, gradual worsening of pain the more it is used, worse at end of day. unable to perform explosive sport, standing gnawing ache, give way on some exertion.
 Tight band behind medial malleolus Tightness in calf that doesn't respond to stretching Pain &/or crepitus at PTT
 Unable to tiptoe or heel raise (pain+++). Difficulty with stairs up + down Pain++++ if wearing flat shoes Pain can be traced along the tendon Pes Planus with some swelling over tendon

Statistic	Value
Total Responses	49

PHYSIOTHERAPY RESPONSES

12.2 Focus group transcript.

A “SJR Physiotherapist by background – here in non-specialist role. I don’t have a huge interest in this area, so kind of here more as the kind of... the other end of the spectrum in regards to this condition.”

B “AS I’m one of the consultant surgeons here, I’ve got an interest in lower limb surgery of the foot and ankle and I operate in tib post probably about once or twice a week and... I don’t have... massive... I’ve probably done about 250, something like that, reconstructions.”

C “GH – an ESP podiatrist based at B & H locality and I help to run a foot and ankle community assessment triage service and I see a lot of tib posts pathologies.”

D “AR I’m the podiatry professional practice lead for S Comm T and I do a clinic in HH from the S area with SB so obviously we get a lot of tib post problems as well.

E Facilitator

F Researcher

“E– here to facilitate the meeting. The next issue really is just an agreement of ground rules very, very quickly for the purpose of the transcription and so on. As F already alluded to it’s about exchanging views, having held a discussion and drilling down to some of the topics, so if I could just ask inevitably if you can try and not talk each other, but by all means interrupt, interject and that’s fine and completely healthy and normal, but if two voices are going at the same time it’s obviously more difficult to pick up for later one. And F’s already alluded to setting the scene, if I might just go over setting the scene before we kickstart. Again, the purpose of the focus group as I understand it is the explanation of your views, opinions on the questionnaire that F already sent out, on the topic of posterior tibial tendon dysfunction, and it includes areas of assessment criteria, diagnosis, progression and severity and then if we have any time, and I’m conscious of the time, to make use of the time fully, we might discuss outcome measures of quality of life, and activities of daily living, as a potential measurements, about whether we should or shouldn’t include them or not. So to really just to kickstart with a discussion, first of all, the first question I’d like to put to all of you, is what do you think of the lack of agreement on what should be included in the assessment criteria in terms of posterior tibial tendon dysfunction. You might be aware of some of the findings, there was a lack of consensus both within and between groups on agreement over the type of criteria that should be included so... really just kickstart then, anyone like to kickstart on...”

B "Have we got the questionnaire here?"

"The questionnaire's not here, but we've got a summary of the results if you would like to..."

B "A summary of the results would be great."

"Yes, a summary of the main points are... so it's really in terms of getting started about... there was an agreement there should be assessment criteria towards this. What are your thoughts about... what are the goal standard tests that... weight-bearing... non-weight-bearing... whatever assessment do you find in your practice or you think is most appropriate in the assessment of posterior tibial tendo dysfunction?"

D "I suppose the probably first thing is that it's when we see the patients I think, and a lot of the early stages, is probably seen within the GP practice, so by the time we get them they tend to be quite a long way down the road and I think that's possibly where some of the lack... if you want to call it that... within the sort of provision of services, actually getting the patients early enough so that you can identify that a problem is there, whether it's from biomechanics or from the work the person is doing or particular activities that's leading to the problem, so that you're intervening only after being able to get a good outcome without too much intervention so... I don't know if that really helps that particular thing but I think not seeing them early enough is my opinion to actually get the full stage in..."

"Fine, so that's really looking at... a bit about... you gave us a bit of the background there, but potential causes and associated causes, but in terms of the actual assessment, when you're sitting down and saying right we're going to carry out the assessment... what's the sort of criteria that you... what does that include in this assessment?"

B "For me, the history, there are one or two salient points in the history I look for and there's a lot of stuff they'll tell you, but the main points I look for is a change in foot shape in a short space of time, anything of a year or less and a unilateral foot shape, so if they say it's one foot that's changing shape.... Ankle pain, that's medially based to start, then disappears and then becomes laterally based as they impinge, and they complain... patients describe... rather like ACL deficient patients complain of this??? These patients complain that their ankle starts to tip in and they all do that sort of motion, saying their ankle is tipping in, so when the patients say that it's tipping in... I think those are three salient features from the history for me. In the examination important stage of things for me are... are they straight and painful? That is to say, and then generally that to me means that the tib post's intact, but it's dysfunctional and they've got pain so they've got some tendinitis. Are they significantly valgus, but correctable? Are they significantly valgus and fixed, which changes their prognosis? And then... their single leg tiptoe rise, and actually then when they're sitting,

whether they've got any active resistance to forced inversion. So I do those five tests. And that's all I do in the examination. I do nothing else really, that's the examination."

E "OK thanks very much. C what's your approach to assessment?"

C "Oh I think that's excellent. I think one of the things that we see as well, a lot of probably the more milder pathologies, so the less obvious sort of changes where you're getting those... the sort of historically grade one of the tendinopathies. So for me it's about good history taking, good questioning, that the site... the episodes of injury, that type of thing that... the site of the swelling, pain, power to resistance, that's very important for me, simple plantarflexion and inversion, can they do it to exclude the rupture, flexibility... is it correctable? For example, the weight bearing tests in the more... later stages, that's very important for me."

E "OK, so so far... and we'll come back to A in a second to get some thoughts, but so far, you're hinting at... both in terms of assessment and some of the tests, but within that there's also some other thinking and reflection going on about what it will mean, what sort of intervention, what sort of stage are you in and the degree of severity, so in that assessment... so looking at criteria in a sense of you're describing certain criteria which indicates a degree or stage in ??? of what's actually going on, we haven't quite separated it out towards staging, but you're hinting at... but there's a reasonable agreement so far of the tests, no one would vehemently disagree with the tests so far that have been both subjective and to a degree objective of patient symptoms and so on. A I know you have a different background and you may not specialise in posterior tibial tendon dysfunction, but as a physiotherapist perspective, in terms of assessing the patient who comes along and you think that's the problem, what sort of assessment criteria do you look towards using?"

A "I think obviously that if they are presenting just with kind of ankle or foot pain, I think within the realms of physiotherapy you would obviously look kind of above the ankle and the foot like... and kind of considering it in the early stage I think we would probably have something that we could offer, but I think if you'd someone in any of the advanced stages that you've all just spoken about, I would strongly say that most physios would by then have decided that probably it was maybe beyond their scope and they would look towards referring towards their colleagues probably in podiatry initially, or if they had access to an orthopaedic surgeon with a special interest then certainly they would go that way. So I think, you know, very much the early stage assessment I would agree with what C was saying, but I think when we're moving into the stage where B is seeing them, I think probably we would be without, you know... we would be looking at a bit beyond our scope really."

E "So you're hinting there at different staging, also you're hinting that staging might be attached to particular allied health professional approach, which is an interesting debate and you might want to

discuss that. You've left aside... rightly so you haven't come across with a biopsychosocial approached assessment, you're very clear about specific assessment findings that lead you towards yes, it's posterior tibial tendon involvement in some shape or form and staging. Can we... before we get into the imaging debate... the key test, B you mentioned sort of a key test that you invest in because you have the... presumably the experience to say nine times out of ten you know... almost know what you're going to find when it comes... Are you hinting at... in any of the assessments, you're linking to any particular intervention at that stage? What are the... if I had to pin you down to sort of two or three absolute tests that say yeah, there's definitely this degree of involvement... what would be...?"

B "It's sort of... the clinical tests were investigated... range ??? tests... clinical tests... My clinical tests, primary clinical tests are... from the history are a) is it painful, b) do they complain of collapse. If they complain of collapse I generally find that they're at stage two, possibly stage three and beyond. And the examination side I find that resistance to forced inversion, so with the patient sitting, non-weight-bearing, and I put the foot in the plantar flexed inverted position, can they maintain that position against resistance? And if they can, they've generally got an intact tib post, they may have a ruptured spring or something like that, but generally it's intact. It may be diseased, but it's intact, and it has a degree of function. And if they are... if they have got hindfoot valgus whether it's fixed or flexible, because that dictates management further on. And those are my sort of key three main things. And the other thing to say, in the history, again I look at things rather brutally. I look at them all with a knife in my hand so I do try and assess them as surgical candidates or not, so if I look at them and think actually you're just too elderly to get through the rehab, or you've got too many ??? illnesses, then it does start to skew me one way or another, non-surgical or surgical, so I do look at them as surgical candidates or not surgical candidates because some of them are just too old, too frail or just can't get through the rehab."

E "And is there anything else you guys would like to add to the assessment criteria at the moment? Is there anything else missing or...?"

C "I think the key thing for me, in my particular type of clinic... it's about getting the diagnosis, so they're coming in with pain, and it's about getting the diagnosis, that pathology and then grading it. I'd reiterate exactly what A said, the basic signs and symptoms, the site of pain that's key for me, signs of swelling, injury, bruising and that type of thing, hindfoot valgus, unilateral heel rise and failure to repeat."

D "You've also got to look at excluding the obvious Charcot problems so medical history's important for that and just comparing one foot from a temperature point of view..."

E "So why do you think... in terms of the findings, if you can relate back to the questionnaire, and there wasn't a great deal of consensus about assessment criteria... where do you think that might

lie? You've clearly got a degree of consensus here about the type of tests that inform you so far, putting aside diagnosis at the moment and staging, but you're pretty... it sounds like to me there's a consensus, correct me if I'm wrong, between the... what should be clearly the assessment criteria. Do you think that... where do you think that... if there is any disagreement, where it might lie?"

D "I don't... what was the disagreement? I'm not quite sure what it was."

E "Staging and severity I think was it, mostly wasn't it?"

F "Yes, I mean there was agreement that there should be one. So there was good agreement that there should be one, but I think it was the perspective that people were placing on what it should include because some went completely for physiological changes down... you know, which was largely around imaging and, you know, what are the... the other biological changes that are going on within the tendon structure, whereas other people were much more looking at a clinical criteria where they're wanting to know what the clinical tests are..."

B "I'd say neither group are correct and I think... it's the other thing is that that clinical... is that history, the examination and the clinical ??? it will... whatever imaging you do I think it's everything together and I think if there is disagreement in that I think both groups... I suspect it's just different health professions looking at things from different perspectives. So I should imagine surgeons are looking at the MRI scan every time and I suspect maybe on the podiatric side you're looking more at biomechanical function of the tendon, so it may just be the different way people are looking at it, and where their backgrounds..."

D "It's what you've got available as well of course, what's your access as far as it's concerned."

C "Yes."

E "So in terms of... you've discussed the assessment criteria. In terms of absolute diagnosis and you're hinting at differential diagnosis, Charcot and so on, what are your thoughts about in terms of with the assessment criteria, what do you hang your hat on in terms of yep, this is clearly the differential diagnosis, but this is so classic posterior tibial tendon problem, is there a... anything about that link between the assessment criteria, findings of all the tests you've described that, and the absolute diagnosis that it... what's your experience of... of getting it wrong perhaps, or getting a different diagnosis, either from a surgical perspective or a podiatry perspective or a physiotherapy perspective?"

D "Depending on the stage..."

C "I think the absolute tears or ruptures are for me, the non-weight bearing tests where just can you move your foot across the mid-line, plantar flexing invert it, they will often struggle to do that immensely and therefore I would think on weight-bearing I pretty much know how that's going to look and I think this is a needing... a referral requirement for orthopaedics. That's the key one for me clinically, it's a quick simple one, to resistance I will then grade it. The weight-bearing tests, failure to rise and invert, sort of key things for me."

D "Obviously you can get that some extent with a tendo-achilles...as well but.."

B "I'd go with exactly that. I tend to marry it with an MR finding so I like... I do like...as these two chaps have just said, to exclude the other diagnoses and your ??? the subtalars, the talonaviculars will all collapse into a plane of valgus probably generally, but they can go the other way, but you'll generally get a plane of valgus in the Charcots, so you've got to exclude your other diagnoses so whilst, I think I'm clever and ?? I'm wrong a lot of the times and so I'll always get a scan to say if I'm right or wrong and probably 10% of the time I'm wrong and then it's one of the other pathologies. So I think your clinical findings, they're just... you guys have just describe, and an MR, and I want the two of them to marry up. If they don't marry up, I then... if on MR the tib post tendon looks normal, I've then got to... and the subtalar joint's normal, there's no Charcot, there's no talonavicular, I've then got to think well this is a true spring ligament rupture and chronic deformity and that the spring ligament's gone first. But I want the two to marry up."

E "A from a... you've sort of hinted at earlier on, you're probably looking at an early referral on, is there enough information in your assessment criteria to say that at that point... would in physiotherapy practice, or from your experience of physiotherapy practice, would it be that one step further to request imaging to aim towards diagnosis or...?"

A "Yeah, certainly and then it would be looking at whether you make the decision to go back via their GP, depending on what services you have available or whether you go down the orthopaedic route really, and I suppose the resistive tests are the tests that we would look to as well and, you know what I mean, if their... like C said, if they're unable to do it, then we would realise that's... we've kind of hit, you know, as far as we can go and that we need to then probably look at imaging as the next option."

F "Can I make a point? I know I wasn't going to participate but you're sort of giving us your views as the specialist practitioners, but what about referrals that you might receive from other healthcare practitioners, particularly relating to A's question around, you know, the diagnosis, how... is the diagnosis accurate? I mean do you get referrals for... this is PT tendon, but actually I don't know how to manage it, would you get referrals for this, you know, misdiagnosis that you then later diagnose as PT tendon once you've seen them? I'd just be interested to know."

C "I'd say a bit of everything, but yeah a lot of..."

D "Mainly general pain I would say, you get the odd one..."

B "Pain, ankle pain...."

D "...flat feet diagnosed, yeah."

C "Flat foot."

D "Yeah, flat foot, but the trouble is, as I said before, that where they've been managed in... by the GP or possibly by somebody else the GPs referred to in the early stages, if they're treating that as a normal tendinopathy, or tendinitis or whatever, they've actually been trying to exercise it out, like you would do with a tendo-achilles, that's when it progresses into the other form, that's when we pick it up, because that treatment's failed because the knowledge maybe wasn't there that that's what you should do with it, and that because of the, you know, vascular aspect..."

E "In terms of... you hinted at imaging, B you mentioned the fact that MRI would be, presumably that's your first choice of imaging, gold... is it that gold standard or does X-ray and ultrasound come into it or...?"

B "I tend to do a weight-bearing AP ankle rotophograph, looking for... and describing ??? navicular drops, or is the talonavicular ??? where you get abduction occurring in some transverse tarsal joints, so I always do an AP weight-bearing rotophograph, I don't really care about the lateral because generally you can't see the subtalar joints, you can't see if there's any degeneration, sub?? because it's ??? it overlaps, so an AP standing weight-bearing... and I then to get MR. I only get MR because I can look at them. Whereas an ultrasound looks like a snowstorm in the dark to any.... The only person an ultrasound is useful to is the person who's actually doing it. They're the only... because it's a dynamic imaging tool, so the only person who can see it... and so I don't do an ultrasound because I don't trust the ultrasonographers enough and I do an MR because I can look at it physically myself and I can see it. I can't see anything.... And it's nice to be able to say that's it, I know the diagnosis, where I look at an ultrasound and I think well yeah it could be fetus...."

C "I'm glad you've said that."

D "Because actually... I have a machine in the clinic I work in, I'll go straight to ultrasound just to have a look at the tendons but..."

B "I think maybe if I had that service I'd use it... I just don't have that service."

C "It's dictated by just that, what's available in our practice. We've only just recently had MRI, that our request ability... so we've relied hugely on ultrasound and I think the musculoskeletal ultrasonographers and consultants are quite good in B & H. We've had really no worries there. We now have MRI ability and we probably would use for those where we're... perhaps where the ultrasonographer has suggested MRI if they've gone... if they consider a tear is present."

D "You see I would say the thing with that is... if you're considering surgery, getting an MR is... you know, is obviously necessary, so you get it, but if you're... if in your practice you're not, then I would... why are you actually doing the MR scan because you know...?"

C "Well I don't think we do it a lot, I'll be honest, but I think... it's there now... we've only just had the ability for MRI but I think if it's a grade where there's a tear I tend to... tend to sort of suggest MRIs to give an opinion as well..."

B "So in your clinic with S you do an MR... you do an ultrasound on the spot and say it's torn... I mean I think as a goal standard of treatment I think that's probably going to be it, where you've got a surgeon and a podiatrist sitting together and you say I think this is tib post, you ultrasound it and you're good at it. I don't have that facility in my clinic. The advantage of that is a) it's much cheaper, b) it's less to see... there's no second appointment, you diagnose it, get your clinical investigation on the same day and then you move forward with the treatment so your time delay... you cut out ten weeks of waiting. So I think it's a goal standard, as long as then any time... I presume any time you're unsure you then say actually I'm going to on and MR this, or I'm not sure about the subtalar joint, I'm going to have look at the ?? and MR. And you probably may... you may then rescan one in ten. But that's probably the cheapest and most efficient way to do it. What I've got is second best because I don't have... I don't have you available."

E "So are we getting to a point where... am I right in thinking that the imaging, and if using MRI and using ???? and like you're saying an ultrasound, that the purpose is twofold, is what with one to confirm your diagnosis and secondly it's also going to inform the particular intervention and management as well."

General consensus – yes's all round

"And that's how imaging is used. And is there universal agreement with posterior tibial tendon dysfunction in terms of the evidence base that you're aware of, literature about the preferred imaging? I mean if I asked you what do you understand is the national norm, if there is such a thing?"

B "I think 70% of people will do an MR because they don't have this... on this real time... where you've got this real time ultrasound facility which is probably goal standard just in terms of management, but I think probably 70% of people will MR and 30% will ultrasound, from the people.... ??? S and all the other foot and ankle surgeons. But I must say I'm getting to the stage now where I'm happy to progress without MR and without imaging I think. The number of times I look at a scan and I think it's different to what I thought it was, is getting smaller and smaller all the time."

E "So you're hinting at you really rely on your clinical judgement and experience?"

B "Yeah even... if the scan comes back and says there's a little bit of tib post tendinitis and it's function... function is to me... and actually I consider them as having a functional tear and it's of no use to them so they need surgery anyway so... I must say, I'm moving away... I still do MR them unless..."

E "But it's... you feel it's less critical for your practice. A... what from a physiotherapy perspective, with use of imaging and say posterior tibial tendon dysfunction, in terms of usage of it, interpretation of it, common usage, it's left to other people... are you aware of... what's the sort of general physiotherapy take on imaging and people who do..."

A "There's generally a move in physiotherapy to use ultrasound, but I think it's more that the physio's interest lies away from the foot really, just because we do have colleagues who specialise in the foot, so I don't think you get that many physios who would specialise in that. You're really looking at a far more kind of around the shoulder, round the lumbar spine, that kind of area, you know what I mean, where physios have more of a specialist interest in. But certainly there are more physios training to be... and to do ultrasounds as part of their practice and part of their clinical practice and to help them with their decision making and kind of using it, really for patient benefit, to be able to give them kind of explanation and understanding first, you know, in the process, than kind of a longer drawn out process, going for scans, coming back, going and seeing the consultant, coming back, you know, and there's... it kind of ties it all up a little bit neater, so there's certainly a move towards using it more, but I wouldn't say within the foot especially."

C "I was going to add there as well, the ultrasound is very helpful for us to decide when to refer on, so is it just a tendinosis, is it just synovitic, or is there actually a tear and can they sort of give you an idea, an estimation of the degree of tear. And that allows me to think right I need to refer this straight to orthopaedics or we'll manage this in-house."

E "So this growth... this use of imaging in terms of we look now, and it's still in clinical management, and it sounds like you've all got different models of what you use and who interprets them. Sometimes it might be a joint decision and sometimes different healthcare professionals

involved, but where are we going with this in terms of who ultimately takes responsibility for interpretation of any of the imaging? Are we going far away from the traditional days of the radiologist saying here's the report? Have we moved away from that? What's the...?"

C "Well I know as a podiatrist I can't offer an opinion, I rely solely on the.."

D "With the ultrasound, you wouldn't say.... You can't anyway because it's only when you're actually doing it you can really see what it is... it's the person who does it has to do the report really, on that basis. For... just to go back to what you... the other question which was about what is, you know, what is a generally accepted view, I think the sort of summary or ?? of the international view is that early on ultrasound to see whether the tendon is affected is usually used, x-rays to look at... in later stages to see where coalitions have occurred or ????, MR isn't considered to be a normal imaging modality during that diagnostic period, but obviously then is... if I remember correctly, is when it's directing surgery or perhaps you just want confirmation. That's as I understand it, that's from looking at, you know, the various paper... I think Doug Richie summarised it recently didn't he, in one of the magazines, looking at the staging and that's I think...it's the information pulled together from that."

B "Is that based upon the accessibility of the imaging though?"

D "No. I think that's just purely what... you know, it's done over a whole load of papers, different papers and things so it's a..."

B "So you... when it gets to my stage, that surgically... given the choice, what I'd like to have is a real time MR, so what I'd like is one of you guys, so I'd say this is tib post, I want an MR ten minutes later, and then come back and see me, the same thing with the ultrasound, and the only reason, and that would be money... as long as money wasn't an option, and we're just aware that money is an option. And the reason I would do that is, first of all it tells me a lot about tib posts, it confirms my diagnosis. Second, it tells me about the muscular belly of tib post above it, so if the tib post is diseased, but the muscular belly above it is fibrose, then it's of no use to man or beast. So it tells me a little bit of what's going on in the calf muscle as well and thirdly it tells me about the other joints, even though it's not an ideal imaging for bones, it does tell me about the STJ and the TNJ so I cover that base as well. and also it tells me a little bit about...some of the radiographers or radiologists are good at looking at spring... I'm not... but the rest I can interpret from an MR so, in an ideal world I'd have an MR on everybody... if it was a... if cost wasn't an implication. Because it gives me... I think it covers everything I need to know."

C "And I wonder whether, with the advent of the peripheral sort of MRI, you've got the loading of the foot and ankle, sort of ??? MRI that's sort of around, whether those may change."

D "Yeah, I'm sure it will change, it will evolve won't it, to be able to..."

E "Well that's very interesting because that kind of leads into I hope... when I say hope, it will be... a really nitty gritty nuts and bolts of the discussion of the group because it strikes me from what you're saying... I'm trying to summarise, but not put words in your mouth, that would be fatal, but you've gone beyond imaging as a confirmation of diagnosis, it's much more than that and what you're hinting at... by depending on what might be a goal standard tells you much more about the appropriate options, it might even be linked to outcomes, it certainly tells you the surgical approaches, and so it's... it's very intimately linked with management choices as well as the diagnostic process. So bearing that in mind with the role of imaging being much more than merely confirming diagnosis, that leads into discussion I think to try to untangle or disentangle the assessment criteria linked to staging and progression of the disease and it looks like from the questionnaire that there's an acceptance in the literature that there's a...all... there's no natural progression of the disease that can be completely predictable. It varies with different pictures from patient to patient. Can we explore, with your experience of post tibial tendon dysfunction, in terms of if there can be staged and looked at severity, what, if I had to pin you down to the beginnings of the areas, which will include imaging, what are the sort of key... we can start off with if you agree a staging of stage one, a mild post tibial tendon dysfunction, can we first of all look at that, and then I'll steer you later on past that if I may... in terms of the mildest, or so-called stage one, what would that look like? What would be the absolutely classic assessment criteria? Both subjective, objective and/or imaging?"

C "It's a flexor sort of gutter swelling, no real postural deformity..."

D "And there may not be any functional problems, that may just purely be pain along the line of the tendon, and that's quite often described by the patient, it just hurts along the..."

E "So some symptoms and no functional change, is that what you're suggesting?"

D "Very early on..."

B "A normal shaped foot..."

E "A normal shaped foot?"

B "Shaped like the other foot."

D "Yeah."

E "Right. So that's interesting, so that first stage, and you're saying there may be no functional abnormality at that stage. There may be some symptoms reported by the patient in a particular anatomical region and you're saying that... is that exclusively the key... is that the most important findings for stage one, or is it anything else in assessment you want to include?"

B "They'll have normal tendon... so they'll be able to do a single tiptoe rise, generally, and it may be painful to do, but they'll be able to do it and when you compare it to the other side it may be more painful, they're going to be slower and it's going to be more difficult, but they'll be able to do it generally I find. Pain again, sort of flexor gutter, swelling in the flexor gutter and the other thing to say is that the foot looks like the other foot generally, and bearing in mind there's a high percentage of people with planovalgus deformities who develop tib post dysfunction. So they may be bilaterally valgus, but as long as they look the same to the other side then..."

E "Fine, so really, I'm honing you then for this absolute criteria of assessment for this early stage, you're not looking for necessarily any functional abnormality, you're looking at really objective... sorry subjective symptomology purported by the patient to be the key assessment of that stage one."

C "I think what... for me personally, it's about excluding all the other nastier versions of that, so you... it's sort of tick box, it hasn't got that, hasn't got that, hasn't got that, we're left with that. That's probably the way I look at it, first."

E "OK. And would imaging come into stage one assessment? As part of the criteria. Or not?"

B "I do imaging... I do... so I would do an MR, again just to make the diagnosis I think it's tib post tendinitis... or tendinosis, but I think... I'm not good enough to say whether that's one of the other things that's going on, so I would MR them..."

D "Well I...yeah I mean personally obviously because I... having the facility, I would do a quick scan just to see, you know, whether the tendon looks normal, is there any tenosynovitis, make sure it's not, you know, maybe the other extensors..."

E "So it's almost gone back to C's diagnosis by exclusion almost?"

C "I mean I would look at sort of symptom severity. I mean I don't have imaging on site, I have to refer them for that, although it's quite quick. I would be looking at how it affects the patient, you know, is this something that we can manage? Perhaps with foot orthoses, change of shoe, but if the symptoms are quite marked, affecting like a runner or something, I might look at then imaging them, so I..."

E "So you're suggesting different hints at what type of... what stage of intervention, depending on... not just a... can I ask you... can I drill you down to... if you say you're looking at pain, albeit very subjective issue of pain, do you use any particular... I mean do you record a pain scale severity, or do you just say... it's affecting my life... I mean what's the... stage one, what sort of... how are you going to capture thinking well that's the sort of pain I'd imagine was..."

B "I say it's painful... as long as the pain's medially based. As soon as it hits laterally based pain then I get more suspicious. So as long as it's medially based pain, I'm happy. And patients differ. Some people are good with pain, some are bad with pain. But as long as it's pain for medially... over tib post."

E "And if I pushed you to say at stage one how... to what extreme could pain be present at stage one of this condition?"

B "For me... I find the patients say... some of the patients say it hurts after activity, some people say it hurts all the time, and so I think it's widely variable, for me."

E "But you're still sticking at the... that variation of widely variable pain, will still remain in... because of the lack of functional abnormality or partly... it would still remain in that stage one?"

B "Normal function as C said, yeah, he's excluded... he's made sure they've got normal function, so the function of the tendon is intact and working, but there's pain."

E "And would you guys agree with that?"

A "Yeah, from a physio point of view it's just ruling out everything else, a bit like what C said, and then coming down to that... possibly is that the problem and then that would be when I'd probably be looking towards referral onwards."

D "I mean the question is... does... is stage two simply because you've then got a functional change? Or is there an overlap between, you know, high grade one, that's where it gets a bit iffy isn't it, but if you... you know, if you want to then, you know, be dramatic about... and make that distinction, actually if the function is normal, then it's stage one, I suppose you could do that."

E "OK, before we get into the next stage, I suppose it must be mentioned, mustn't it, discussed... presumably although one mustn't make too many presumptions, that stage one of pain and by variability of pain, depending on the patient, we know how complex pain may be. That's going to presumably form the matching up, the intervention at that stage, the treatment at that stage? Am I right... if we get a chance we might spill into that or not. OK, so you've carried out this assessment, you've diagnosed by exclusion, you may image all the patients because you want to

ensure that there's nothing else going on that you can see, and you're really going by patient reported symptomology as the number one criteria for that... remaining in that mild stage, stage one. The next stage, where does assessment change and what criteria are you beginning to utilise for saying this is the next stage of severity?"

B "Well for me it's, again, it's ??? dysfunction, so as soon as they are, they struggle... clinically they say, it's starting to collapse, examination-wise they've got correctable deformity, but dysfunction. They may still have some function, but it's not normal function, so they may just about be able to go onto tiptoes or they may not be able to go onto tiptoes and then, radiographically things start to change, the talonavicular uncovering, and other MR and ultrasound features."

E "And those features, if I had to push a tab, so identify those features, are there any more on that stage you mentioned, you began to describe some of the findings? Are there other findings that you want to add to that stage?"

B "So clinically, in the history, what changes they describe, they all do this, they describe this tipping out of the ankle joint, so they describe instability in the ankle, collapsing inwards, they describe... they may describe a laterally based pain, so as soon as they describe laterally based pain I'm moving through the staging category, definitely at stage two..."

E "Why is that so strong, that'd definitely stage two?"

B "I find just clinically, from my practice, I find that as soon as they start to drift in significant valgus, they develop the sort of calcaneal figure impingement and that's very painful and it's more painful than the medially based pain. The difficult patients are the ones that come and say I had medially based pain and it's gone and I then break the bad news that the lateral based pain is much worse. And it is much worse..."

E "Because?"

B "It's just more painful, again they don't tolerate it as well, it's just a progression of the disorder. So clinically, in the history, I look for that. Examination-wise I look for old ?? tib post function, that is to say they either can't, or it's reduced ability to go on tiptoes, reduced ability to forced aversion, to maintain that foot in the plantarflexion inverted position, and then radiographically I tend to find that they'll look... they'll have talonavicular uncovered in the standing weight-bearing AP rotophograph, and MR ultrasound I'll start to see changes, generally.

E "So that's a fairly comprehensive picture of stage two."

C "I'd reiterate that perfectly and then I think I'd look at the functional aspects as well. The functional ability of the patient, how it's affecting them as well."

D "Yeah, because usually it would be affecting one of their activities by this point."

E "And other professions at this stage, you've got stage two because you clinical findings... would you be then requesting, if it's available in your area or not, some imaging, or not? And which imaging modality would stage two... would it direct you any differently?"

C "I mean I totally understand why you use the radiograph because it gives you a nice clear picture of the sort of talar, sort of plantarflexion and abduction. I probably don't do that because I'm not looking at it from a surgical perspective, I'm classifying the diagnosis, so it's ultrasound I think for me then. Because that's what I've got available."

D "I would say it's also fine if you want to refer them for surgical repair of the tendons, so that's what you... if you say well this is definitely torn at this level, obviously you're going to support, immobilise, whatever, to stop it getting any worse and then send them through."

C "It's going to dictate your management isn't it?"

E "And would imaging... in physiotherapy practice A from what you know, would... if from stage one with that pain being... and no apparent dysfunction, would a physiotherapist generally speaking, would they see that in the realm of their practice and not refer on at that stage, or would the general trend to be referred to someone specialising in this area, at stage one, do you know if...?"

A "It's difficult to answer on behalf of all physiotherapists, I think it depends on how confident they feel really. I would say that on the whole I think most physios if they are presented with foot conditions will attempt to see if they can manage it. Obviously they have anatomical knowledge as well and they would explore it and, you know, go through a process of trying to work out maybe what tendon is at fault. I think when you're going down into the nitty-gritty then of foot dysfunction when you're getting pain presenting on medial or lateral aspects with kind of coming and going, you're getting these different presentations as they move through, then I think most physios, unless they had a special interest in that area, maybe they work with a specific client group like runners or something like that, would probably feel they've probably reached their limit and would either work alongside a podiatrist if they had access to one to possibly look a little bit more at the biomechanics and things like that."

E "So the imaging would only come in as working as part of a team you think, or specialising in that area from a physio perspective."

A "I think so, it depends on where they see... because obviously like podiatry, physio works privately and publicly so I think if you're within the NHS system you do often have access to the other professions quite quickly, so you probably would hopefully kind of, you know, make that connection and kind of speak to someone about the patient. I think privately is possibly where sometimes these patients will go for longer being probably managed poorly, because maybe they don't have the knowledge base that they think they do and don't recognise that maybe they need to move a little bit faster and that imaging might be appropriate then."

E "Thank you. So just to clarify, absolutely for the purpose of the research, stage one of the assessment, pain symptomology, no dysfunction, no... so that would be classic. Would you still, within the assessment of stage one still go through a fairly comprehensive history anyway. You're not suggesting it would be as narrow as merely just finding the pain being presented and imaging and saying that's it? Presumably there would be... you would... I'm making an assumption, but would you carry out other aspects of history taking assessment as you would do for every patient, regardless of stage of severity? So would that be agreement with every standard sort of practice within that... so... and that would include what you said earlier on in terms of both weight-bearing and non-weight-bearing tests. You'd put through all the patients, regardless of severity...?"

General agreement from everyone.

"Fine, OK so... so stage one, we've got consensus over the pain history. It's clear and no apparent dysfunction and imaging showing no major pathological, or no evidence of pathological change, is that reasonable?
The next stage along..."

D "You'd see some change in the ultrasound, definitely."

E "In terms of...?"

D "Some tenosynovitis possibly. You might even see some thickening of the tendon compared left with right, and be confident that..."

E "So there might be some minor pathological changes that wouldn't necessarily linked to pathology is it, is what you're getting at there at that stage?"

D "Yeah some sort of... there would be some..."

E "Subtle changes..."

D "There's going to be subtle changes in things...."

E "Chronic inflammation and that... the effects... So and the next stage, you're suggesting that here you're going ??? and very clearly looked at the dysfunction and the level of dysfunction. Are you confident about staging stage two, compared to stage one, and also from stage two to the next stage? Is there any sort of telltale criteria you think ah, that's fine, that's definitely in that next stage?"

D "Well within stage two I suppose it's generally still reducing of the... so we'd use the... there is a degree of flexibility to the problem so you can still yourself reduce the foot back to normal shape, but to get to stage three you're actually getting bony changes which will resist that. I mean that's a gross difference I suppose."

E "So before we get to that stage three can I say then at stage two, and you may have some evidence of dysfunction, would there be any necessarily... what would you expect to find on any imaging at stage two? You described some of the subtleties at stage one in terms of tenosynovitis, etc, some minor changes, some subtle changes. What would you expect to see, if we can generalise, with imaging, for stage two?"

D "Tearing of the tendon, fibrosis of the muscle and belly above it."

E "Tearing of the tendon, some fibrotic changes... this is all stage two..."

D "Stage two, yep, yep. There would be, on x-ray you will see changes in the alignment, so on the medial side, as B was describing before, and yeah, MR would give you a much better picture of what's going on."

E "Is there anything else, apart from tears and mal-alignment, is there any other findings you expect in imaging at stage two?"

B "So in respect to stage one and stage two... in stage one you may have fluid within the tendon sheets, so stage two you can also have fluid with the tendon sheets, ??? a bit more... Looking at the tendon again, it's about shades of grey so... as C mentioned and you mentioned the term, stage one, stage two, stage three, we've graded it in definite stages, but it's a continuous spectrum so there's lower end of grade two where you may have a simple linear longitudinal small tear of the tendon, to the upper end of stage two where you've got a tendon that's massively thickened, absolutely enormous, multiple tears running through it, through a long... over a long distance, so proximal and distal to the medial malleolus and a fibrotic muscle at the top, so I'd consider that sort of high end stage two, as opposed to a singular tear, small tear, relatively normal thickness tendon

and normal muscle above it, so I'd put that lower end stage two, so a spectrum within it, and all of this is a spectrum."

E "So that's a... that hints at... is there any link therefore within that high end – low end of stage two... does that have implications for the particular intervention at that stage, are there different interventions for the low end compared to the type of... with the pathological changes you describe at the high end? I'm making an assumption, does that have implications for different approaches to clinical treatment?"

B "Well it does a little. If it's low end stage two, and the hindfoot's only just starting to change shape, I may say well I'm going to give this a trial of conservative therapy, I'm going to stick it in an air cast, we'll do a cast it, or simply do a single decompression and give it the benefit of the doubt, and I'm going to manage this one, sort of low end conservative or surgical sort of decompression, or simply plaster the ??? and absolute rest and orthotics, and I may do that for very, very early stage twos, but for the upper end stage twos where it looks absolutely a mess, and they've got a significantly more deformed ??? I'm moving much more towards surgery. It may swing one way or the other."

C "I think I would reiterate that perfectly. For me it's a decision, can I manage the sort of lower grade stage twos conservatively, air-cast, orthotics, etc, or do I need to refer on?"

E "So would I be right in saying therefore that when it comes to staging of the progression and severity of this condition, the imaging begins to come into its own. It starts off in stage one by helpful for diagnosis of exclusion and helps to confirm diagnosis, but doesn't have a major part to play and stage two it certainly can inform the clinical judgement because you're basing a combination of findings, of both clinical findings, that sounds like quite a lot on your objective findings of the imaging that's going to inform and the particular interventions, so it sounds like from a lay person here that the imaging really is a significant part to play in the assessment criteria of stage two. Is that reasonable... is that a reasonable assumption to make?"

All confirm this is correct.

D "I was going to say as well I'd sub-divide stage two into four different bits now, so you've got to try and clarify I suppose..."

E " So the sum of the... summary of the findings within the imaging is going to help with this assessment criteria of stage two is that... that's where you're at? OK, so is there anything else you want to add to either stage one or stage two at this stage, before I go on to stage three? Anything else we've missed out or you want to reflect on, anything else you want to add for absolute clarity. We've hit stage one has been very much patient pain symptomology, imaging for sake of

exclusion, stage two you've been much more... emphasis on dysfunction and more emphasis on imaging findings, and you've talked now within that stage two of low-end, high-end, you didn't discuss low-end, high-end at stage one so much, but seemed to be more emphasis on low-end, high-end in stage two, so stage two sounds a greater range than stage one. Is that a reasonable assumption to make as well. OK, so in that stage three. What's the picture like with stage three, both in terms of clinical findings of subjective, objective findings and imaging findings?"

C "For me if the articulations are becoming less mobile, so less correctable, reduceable, that's when radiographs become relevant for me, and I... oh I tend to probably, in those conditions, request an orthopaedic opinion for peace of mind, but knowing that they may not do anything, if it's fused possibly, or beginning to ?? or aircasts, you know, which you may be able to do."

D "Yeah, I mean the..."

B "It's probably excluding..."

D "Yeah... it's going... you're going to have subtalar joint involvement possibly, coalition going on, at that level, at stage three. But it's user position that's a problem, therefore it's going to need surgery to actually re-fuse it in a better functional position."

C "Surgery mindful of patient co-morbidity."

D "But it does depend on the patient, because a lot of them are going to be... you know, not really up to having the surgery, a lot of the ones that we see. Therefore, at that point you're looking at what is the best non-surgical option for a lot of them, that you can't refer on."

E "That's an interesting take and change on your management approach. Can we get clarity at all first of all on stage three, and so you're saying this now is some particular changes you might see in the radiographs... is there anything else that's... you'd hang your hat on, stage three, either in clinical findings or in imaging findings that's..."

B "For me stage three is all clinical, so for me the MR findings, no... the MR findings of stage two and stage three can look exactly the same. So for me this is all about a clinical examination, I will examine... if it's a stiff fixed hindfoot I can't correct fully, they're in stage three. And again, a bit like stage two there's a low-end stage three and there's a high-end stage three. So high end stage-three, it's massive deformity, completely fixed. And the low-end stage three is I can partially correct, so I can gain some correction and then I've got to think about whether I've then got two surgical options... you've got the reconstruction versus the triple fusion. And if you're looking at those two option, the functional result's definitely better with reconstruction versus the sub... versus triple fusion. Triple fusion's an awful thing to do to somebody, but we do it all the time because it's

a good operation and it does keep people walking, but I'd rather do this than do that. And if any of the function results are better with that, and this... and the question is then, if they're low-end stage three can I get away with doing a reconstruction versus a fusion so again I will... I'll probably grade it and I'll say they're upper-end stage three, even if I try the reconstruction it will fail, therefore you're a triple. If you're a low-end stage three you can take a risk, you may get away with it, you'll have a better shaped foot, you will have a normal foot and the chance... and I... you know, I'll make an assessment whether they think they'll get away with this. But the MR findings I think will look exactly the same. It may show a complete rupture but it will look roughly the same."

E "That's very interesting. So we've got the imaging having a really important part to play in helping to diagnose... to assess or to define and pick up on stage two. Stage three it becomes less important again in a sense at stage three by the nature of the clinical findings are so clear that it's almost... not say unnecessary, but you suggest a low-end, high-end again and it sounds like you're saying the... or implying that the requirement for low-end, high-end is very much about the intervention, the approach type of surgical procedure, or not surgical procedure, may take place, so it sounds as if it's very critical in stage three where the surgical option becomes really an issue and the decision-making within... grading it to low-end stage three might make the difference of a surgical intervention or not, is that...?"

B "Yeah I mean I... if I look at a stage three, if it's fixed, it's already bad news for the patient. I think the first discussion is can you manage this conservatively? Are they elderly, frail, or they can't go to rehab, therefore they are aircast boot, plasters, orthotic boot, shoe... whatever the choice you make is. And if you are surgical candidates you do then look at them and think actually are you a very early stage three and I could get away with the corrections, a reconstruction here, and you'll get good function albeit not perfect. And then you compare that result to the triple fusion result and there's no question, I think the results of a reconstruction is always better than a triple. The triple's a very, very stiff foot and some people find it difficult to walk on, and it is technically a difficult operation with a reasonably high complication level, it runs at about 6/7%, whereas the complication over here, probably runs at about 3% so it halves the complication rate. So I would look at it from that point of view. I'd rather do this than do that."

E "And it sounds like to me that what you're saying is in part that the decision making process, up to then... you're still taking on board some other aspects of the patient for consideration, but the surgical options become a much more holistic approach to making that decision, making as... there's an awful lot more than merely the findings on the imaging or the clinical findings of the lack of movement, the fixed movement. You really are taking into consideration many other more variables and factors."

B "One thing I would say about the imaging in that point actually, imaging, for me, becomes less important about the tib post tendon, I don't really care what it looks like, what the imaging actually

then gives me a bit more information about the subtalar joint and the ankle joint and what I'm then looking for actually, is this a stage four? And I think it's a stage three, but it's a stage four, so actually, when I look at the imaging I'm actually looking at something completely different, I'm looking for arthritis now, not looking for tendon disease. So actually I'm looking at something completely different, and actually, you may say actually in that case a CT would be better, so actually it's less important for the tendon I think, and more important for the other bits."

E "So, that's a... from a lay person point of view that's quite an interesting finding that posterior tibial tendon dysfunction, when you're getting into the business end of it, the real... you might be looking at dysfunction, but hey behind the scene of the tendon, forget the tendon, look at the rest of the damage that's there in the foot in terms of secondary findings which are of greater consideration. Anything else you want to add, you chaps on the stage three?"

C "Well I think just a sort of... a point, is often for me those patients are typically present... come into the clinic at stage three and those that have perhaps had a unusual foot position for so many years, and often... are not so uncomfortable and are managing and don't wish to proceed with surgery, and so I might take a look at that and manage that conservatively and not worry so much about surgery."

D "Yeah, because I mean... if someone were to come in, and has recently got... been troubled with it, then I'm... then it's, you know, something that... we can't do much about that, you know, we know that it doesn't matter what you stick in their shoes or anything, it's not actually going to have very much effect on them. But if they've been managing reasonably well with their, you know, stiff flat foot for some years, then it might be a case of actually you can make them a bit better with an insole or a change in shoes or something like that so... that's where our influence on the stage three and four comes in."

B "And it may be that we manage the patient perhaps with an injection in the joint, rather than worry about the tendon and keep them managing."

E "Can I ask, again it's maybe a naïve question and I apologise if it is a bit... sounds like the stage three and stage four perhaps might be quite difficult for differential diagnosis, I mean some of the progression would appear to be tendon dysfunction, but we're talking about arthritic changes you might see and thinking about co-morbidities, is there a degree of difficulty of going back to... I mean somebody may appear as stage three as a first appointment with you... does it make the diagnosis easier or more difficult in a sense of there is many other conditions that can manifest in terms of arthritic changes of one kind or another in the hindfoot or not? Would it still primarily be posterior tibial tendon dysfunction that you think's ah that's the picture of that arthritic changes there, those findings? Or is it more difficult to...?"

D "Well if that's how they appear that's the first time you see them, you won't really have a clue what went on before, but I mean stage four is arthritic change in the ankle, as well so..."

C "You can make an assumption can't you, if there's muscle atrophy within the leg and you can make a... you can have a good hunch that it's likely a... and if you look at the history, is there an injury or...?"

E "But is it more difficult then to..?"

B "I don't really understand the question..."

E "I beg your pardon, what I'm getting at, right, beg your pardon, when it comes to staging of posterior tibial tendon dysfunction, we're trying to ascertain the criteria for that assessment to diagnosis and tests and so on, I'm looking at stage one, stage two, stage three, and I'm just putting to you that it sounds like from stage three and stage four where there are more pathological changes and arthritic changes, it comes into the argument and the debate is does it make the differential diagnosis more difficult because there are other foot shape types that appear with arthritic changes that may not have had posterior tibial tendon dysfunction in the first place? That's my point."

B "I think so. I think you can then... as soon as you've developed an arthritic ankle, you can then, if the patients say, is this... did this patient start off with an arthritic ankle and they've gone on to develop tib post, or are they a tib post and they're stage four? I think then it becomes very difficult. The good news is it's probably slight academic, from our point of view, in terms of management. In terms of progression and from trying to work out the disease pattern, it's much more important obviously, but I think it probably becomes very difficult to work out, and then you've got to go back to the history and say well actually I've always had a normal shaped foot and then it became flat and now it's compared... you may be able to gain something from the history, but management wise it probably becomes more academic. I think... your point was actually very important C which was about if you get somebody at stage three, actually it's stage three, it's a horrible looking foot, it's fixed, horrible, in fact... I'll show you some pictures of the ankle I've just seen in clinic, and you know, their feet look horribly deformed, and you think how of earth can you walk on that? And it's interesting, you see the same thing in sort of revision hip arthroplasty where patients have a destroyed hip and it's been in for years and it completely needs a redo, and actually you have to think very carefully, if they've got that far, they've gone through all the painful stages of stage one and stage two... if they've gone to stage two they may be somebody who you can manage conservatively even though they're at that horrible stage three, they've learned to live with it, developed coping mechanisms, they've got shoes or orthotics and they may be appropriate for conservative therapy."

E "So if, for argument's sake, debate's sake, if stage three/stage four, and you've got this horrible foot and the arthritic changes and ignore the fact that we might not even know if there's been posterior tibial dysfunction in the first place, but on the other hand there's a... you're suggesting that these would be the classic findings in stage three and stage four of posterior tibial tendon dysfunction, is that... how do you know that would be the necessary progression of the disease if there's no intervention, that it would progress into that picture as opposed to something else taking place? How are you so sure that that's a... equates to stage three of posterior tibial tendon dysfunction if you're also saying, at the same time, the differential diagnosis is quite difficult and might not even involve the tendon in the first instance? How do you know it's going to be a progression? Why are you hanging your hat to that?"

B "So the examination and your investigations should help you with that, so your examination should then be able to exclude, for example, subtalar pathology, or talonavicular pathology or Charcot's arthropathies from the history and things like that, so if they've got any ?? arthropathies and they're diabetic they are ??? so you should be able to gain some information, and radiographically you'll be able to look at the tib post tendon, and somebody who's stage three tib post disease will have a tendon that looks appropriate on MR or an ultrasound and whichever imaging modality you choose, and so if you look at a stage...what you think is a stage three person, and you look at their MR and you think that's a normal tendon, you've then got to really question your diagnosis. Are these now another pathology, one of the three we've mentioned, or are they a long term planar valgus deformity, it's a bilateral feature and now they've completely stretched and torn their spring ligament which is something that often gets forgotten, you know, is this a pure spring ligament rupture and a pure midfoot rupture, all the medially based capsule has gone."

E "So if you're working towards a classification, writing this up and saying hey I'm looking at stage three, stage four of posterior tibial tendon dysfunction, and we've had a debate about the difficulty of the differential diagnosis, and B you've come back to very clearly highlight the fact of where you go back to assessment findings and exclude the various disease processes that could account for the changes, would you want that sort of... to put that criteria in... in stage three and stage four, instead of saying what you might find, here are other things to consider as criteria for coming up with saying this is definitely stage three and stage four posterior tendon dysfunction, as opposed to saying well here are these... are you with me? So in other words, if we're looking at clarity of our... the criteria for stage three and stage four, whilst you're acknowledging it's quite straightforward in terms of the... associated radiographic changes and associated bony changes, but you're saying to help to exclude other possibilities of leading to that condition, you might have some notional exclusion assessment to fill out in describing stage three, stage four. Would that be a... reasonable debate?"

B "Yeah, I think if you're going to put out a set of guidelines for people, for say general practitioners or orthopaedic surgeons are a good example, because of us know nothing about the.... If you put a set of guidelines, for example, stage three, it would be yes... a proviso at the end, exclude subtalar pathology, exclude talonavicular pathology, exclude Charcot's arthropathy, exclude pure spring ligament rupture as, you know, as an aide memoire, because if I look at my other eight colleagues here, it's one thing that gets missed out in medicine and I knew nothing about it till I became a consultant. Most medical practitioners don't know much... SB's probably one of the few people at HH that does. And D."

E " And would you guys go along with that stage three, stage four, if you're wanting to hang your hat as being a result of a progression of this disease, of posterior tibial tendon dysfunction."

D "You can only do it through history, by knowing that they had the previous stages really, that's the only way of really knowing it."

E "C?"

C "Yeah, I would agree, with the imaging, for me, excluding everything that B said and coalition sort of fits into the arthropathies really."

E "OK. A, in terms of, you know, stage three, stage four, would physiotherapists might come... might well come across..."

B "That's what we're talking about.... *Shows the group an image...*"

E "Oh lord."

C "That's a beauty, how old is she?"

B "She's 13."

C "Oh crikey."

E "Heavens above."

D "And that's not a coalition, that's actually a...."

B "No, no, she's completely flexible, in fact, just out of curiosity because I've just seen her now, because she's actually a genetic abnormality but just out of curiosity, she's got... I'm not going to ??? she's got apophyseal dysplasia so... anyway, that's the sort of deformity we're talking about."

E "That's fairly gross.... In both ways... A from a physiotherapist's perspective, patients with stage three, stage four coming up, would that be straight to referral? Or managing from..."

A "I think they're probably... they kind of fit probably more within our remit again at three and four because I think if they are going to be conservative managed, there's lots within physio that we can offer them in terms of kind of aquatic therapies and, you know, towards looking at them more globally, not just looking at them as a foot, because obviously these people with feet like that are not just going to have foot pain, they're going to have pain in knees, hips, back, you know, so... I think that's where we come back into it again and can be a useful professional group to be involved, where it's not so foot specific, really anymore, that your long term management needs to incorporate the whole body."

E "So the management's going to be a multidisciplinary, interdisciplinary approach? OK."

C "Yeah I'd agree with that. I mean one of the things I do look for with tib post dysfunction or valgus feet, is looking at glut function as well, you know, because gluts function synergistically with tibialis posterior so..."

A "Yeah, definitely."

C "... so if they're... if one's a problem there's usually something you can do with the other."

E "Stage.. is there a stage four? We've talked about high-end stage three, is there a stage..."

D "Technically yes it's really involving the ankle."

E "Technically yes."

C "It's extrapolated isn't it?"

D "It's really involving the ankle."

C "Yeah, exactly."

D "It involves the ankle joint, rather than the subtalar and those more distal, so it's a... if it starts to involve the arthritis or a fuse of the ankle joint that would... what's classically described as stage four."

E "And is that the agreed criteria in the current staging?"

B "Ankle will become arthritic, you've got ankle degenerative changes."

C "Yeah."

E "So it sounds like stage four is done and dusted, very easy to get agreement and consensus of stage four, that degree of ankle involvement, full stop? Is that, or not...?"

B "Yeah, I think symptom-wise for me, again I see very few stage... I see very few stage ones, and very few stage fours. Most of mine are twos and threes so with the stage fours, from a history point of view it's very difficult to be certain so I've found my histories less useful because they're painful, they're deformed and they're fixed. The only subtle difference is when I move their ankle joint it's painful as opposed to when I try and move the subtalar joint. And generally when a patient's foot hurts and it's difficult to decide one between the other, so radiographs then become more important again, just a plain x-ray or even a plain MR or CC so whichever imaging modality you use. But it's ankle changes... strongly there. And it... it then again dictates whether... for your conservative therapy, it makes no difference at all, if it's surgical therapy it's a different kettle of fish then, you're then into pan talar fusions, horrible, horrible things."

E "So that's the severity. OK so we've got a sort of... we're doing pretty well for time which is great."

F "Could I just... just before we move on, could I just ask a question. Er... two questions. Everyone's kind of using the existing criteria which, you know, when it was originally proposed in 1989 there was three stages and that's then since been modified twice, which presumably has happened because there was a suggestion at the end of that first paper that perhaps there is other stages and actually we don't know enough about this condition to be able to identify what it is. So over the time that we've been involved and have now got a better understanding of this condition, do you think that there are still things missing from those previous modifications that, you know, could now be considered as part and parcel of this pathology and its presentation that currently aren't really part of the mainstream?"

D "Well I just think there's... I just... personally it's more useful to get better... a better idea of what's happening in stages one and two because those are the ones where you really need to get the intervention early to stop it progressing to the others. As B said, once you get on to three and four it... you're really limited to clinical presentation and functions and what you can actually do about it is quite limited. Whereas, if you have a better idea of the staging earlier on, you can get a much better outcome with the appropriate conservative treatment. So I don't think that actually saying that, you know, stage threeB is this or stage threeC or... you know, what if you were trying to break it up more, or decide that the higher stage... I don't think that, from our perspective's

particularly useful. I think you might do it just from a purely academic point of view, but from a use to the patient, it's really getting that... those earlier stages nailed and interventions appropriate at that point, worked out."

C "The gradings a sort of blunt tool in a way and I think the spectrums in between..."

D "I don't... I mean I don't think I ever use a grading from that point of view, I mean I just look at the individual case. You might put it in the notes, oh this is probably a stage two or whatever, but actually what you do, it depends on your clinical experience and, you know, what's appropriate for that patient. I think the problem comes when these patients are seen outside of specialist clinics and the intervention isn't appropriate and that's when they start to progress."

E "It might be quite timely just to kind of... it slots into the next topic of a sort is... and it's just on that really, I guess the argument might be that if you don't have a classification system or a staging system, whichever you want to call it, then how can you perform audit properly and/or maybe use it as a clinical management tool? I mean if you're using case by case and making your decisions, is one thing, how could you audit, if you have a range of stages... of different presentations of severity of this condition? And you're looking at outcomes. How would you audit without a staging or classification tool?"

B "You can't. I mean that's where the staging... as in, you know, I love the staging, I love classifications, I'm a box/compartmental person so I do love them. Interestingly in my clinic letters I never dictate the stages in post... but I dictate the criteria that I think make them a stage, so I say whether they're flexible or fixed, whether they've got function or they've got no function, but they've got pain and so... I tend to do, but I think for the purposes of audit, comparison, results, you've got to have a form of stage system, because otherwise Joe Bloggs in America versus AS in E, will be compared at the ??? So you've got to have a system. But it is a continuous spectrum, but we try and make it compartmentalised which is a good idea, little failings within it, in as lower end stage two, upper end stage four, or whatever..."

C "And it's also about how the patient manages it I think, as well, in the lower stages. You know, the subjective."

E "But look... can I go back to B and you said, the difficulties of that... the lower stage and upper stage within the staging... you made it very clear that the purpose of that was going to help towards the particular surgical intervention that you would take."

B "Yes."

E "What... would there be any... are you... is there any difficulty in getting agreement between what constitutes the lower end or the upper end of say stage two or stage three, because you were very clear in your articulation of the imaging findings of the lower end and the upper end earlier on, so... but do you still think there might be difficulty there?"

B "I think when I look at... you could make rigid criteria, so you could break down the four-stage criteria, classification we have at present and include the four grades of grade two so that you've got a seven grade classification system, and you could probably break down the stage three as well into two grades, which would be nine grades. And as soon as you've got more grades, the more difficult it is to wield that tool, so suddenly you'll have people... and why are they different? So having just four grades is useful, it's a bit like a mild, moderate and severe, it's much easier classification. But I will use that tool to say right this is a low-end stage two, I'm going to treat it like a stage one, because it's in the patient's best interest, so if they get away with it, they haven't had a horrible reconstruction, and at the same time I may say it's a low-end stage three, I'm going to do a stage two reconstruction, because the reconstruction is better than a triple fusion. I'm not going to treat him like an upper end, so I will use the spectrum and the staging classification to try and dictate management definitely. Although in my letter I won't say it's a low-end stage two or an upper end stage three, I'll say... I'll use the criteria that I use, I'll say it's flexible or it's partially correctable and things like that."

E "And your reason for that is you're more specific in your letter by not putting the staging in, or your reluctance is...?"

B "So the reason, so... actually so the reason why I... on the day of surgery when I go back and see the patient, before I put a knife in the patient, I make sure I've got the right diagnosis. So I'll go in to the patient and I'll re-examine and say what I thought was previously partially correctable, so they may have a waiting time of let's say six months, I look and think, actually no you're really fixed, you've now moved on to upper stage three, this is an inappropriate operation for you, but I'll also look at the letter and think why was I going to do a reconstruction and not a fusion? Oh I see why, I think they're low-end stage three, I'm giving them the benefit of the doubt, the function result is better than that, so I'm electing to do this surgical procedure. So it's more for me to be able to reflect on and go that's why I did this, and that's why it's appropriate or inappropriate."

E "So you guys... would it be... I mean is... are currently using, do you currently use a classification system, to either inform or aid your management decisions or for audit purposes?"

C "I do normally classify the patient. I try and classify them into a stage one or two."

D "??? record about that one, just in the notes."

C "Yeah, I don't usually right back to the referrer, I don't believe a lot of the people referring to me would probably be aware of it."

E "So what's... in general terms then, I mean this an open-ended question, but in general terms, I actually know nothing about the topic, but do people with say stage two, do they tend to... I mean, there's a notion here that without intervention in light of the functional changes of posterior tibial tendon dysfunction, that they will progress to major problems unless there's intervention. Is that a reasonable assumption to make?"

C "Yeah, I think for me, you know, I see probably a lot of stage ones, and I probably would classify it as a stage one and try and validate my management, so keeping it simple with orthoses, advice, etc. And when it's moved on then I'm looking to sort of qualify why I'm looking at referring onwards, or using aircasts for that purpose."

E "And to be devil's advocate, is stage one, in treatment, and perhaps in some of stage two, is some of the conservative intervention, is it just a holding, delaying system/process, or does it inevitably go on to require surgery, or can interventions long-term...?"

C "I do believe interventions, especially at the stage ones, we can make a big difference."

E "But that's not the... but will they....?"

D "I don't know there's any evidence to say so...."

C "No I don't think we sort of specifically audit that so..."

E "OK, from a surgical perspective... viewpoint... is there an inevitability about this?"

B" Yes, I see less of the stage ones. I think the stage ones... we sort of keep splitting things up, but I think the stage ones for me fall into two categories of patients. the first category of patient is the true tib post spectrum disorder, that is to say they are female, over 40, overweight, whatever the... so whatever criteria it is, I've probably got in my series of 250, I think I've got 15 men maximum in my series, so are they a true tib post spectrum patient and they're on that ladder and they're at the bottom and they're going to go that way? I think those are the really important ones to start to really guide their management. Or are they tib post stage one, that is an over-use and I think they're two completely different groups, so they're the... it's the 40 year old fat person like me that starts running for the marathon and starts... and I see them all the time and... mid-life crisis for me, and I start running marathons and I get tib post disease and I'll probably see... Before the London Marathon I probably saw four, and so... and I think they're a different person to the other person who is on that spectrum, and these have got tendon inflammation secondary to over-use

and activity that they're not used to, and these are somebody who've got tib post pathology and are moving along a spectrum."

E "And those ones, do they.... Is it an inevitability that without... that they will require surgical intervention?"

B "I think if you look at the success rate... of the people that will progress onto true tib post pathology, of those two arms... I think 95% of these people will be managed appropriately and will get away with conservative therapy and orthotics and rest, and that's one lot of treatment... and I think of this group over here, I think the success rate's much lower. I think you'll find that 50% of these will progress forward, despite having all the same treatment as the other group... as the other treatment arm, and I think they're two completely independent groups of people."

D "And they are. It's getting the differentiation that's difficult because they're actually a different treatment, because at that point, the ones that are say over-use, you can use normal treatments on those, partly..."

E "So you're almost hinting at a variety of different predisposing factors here, in aetiology, in one group, and it might come towards some shared pathology, but you're hinting at there may be some other, either biomechanical anomaly or other that's leading them into the true posterior tibial tendon pathology. Is that what you're saying?"

B "I think they're completely, if you looked at them... these two groups of patients, for example, if you starting sectioning their tendons you'd find different tendon qualities, this group over here, the over-use, athletic bunch, they'll have normal tendon quality, but it's not used to that activity. This group over here will have true tendon pathology, whether you can see it or can't see it on MR or ultrasound, if you sectioned them you'd see microscopic ??? or degeneration of the tendon, and they're part of a spectrum of disorder."

E "And would... but there's still the assessment criteria you've gone through this morning... would still fit the bill?"

B "Yep."

E "But the ?? stream like..."

D "You can separate them by history."

B "Yeah, exactly."

E "The history would separate it, so you're back... so history seems to become important in both. History now seems to take a greater importance in both stage one, to separate out those that may go on to stage two or remain at stage one sort of, maybe. And at stage four, to distinguish between the other pathologies that might be resulting... other comorbidity, other disease processes that might result in the same. So you're hinting where history comes into it and so on, and really important all the way through, but particularly in those two distinct categories, arguably, albeit under the same label of stage one and at stage four, the history taking comes into its own again. And similarly, imaging starts off as not particularly crucial at stage one, but is important for exclusion criteria and diagnosis. It comes into its own in stage two and stage three, the low-end and high-end of stage 3 to look at the radiographic change and the pathological change that may be different in the two stages which informs the clinical management. And then at stage four you're looking at ankle involvement so the imaging is clearly... is going to help to inform the surgical management accordingly. Is that a reasonable summary to date? If I can go towards the... before we end, other outcome measures that we had a small finding in the questionnaire about quality of life, activities of daily living, whether that should come into assessment and if it... or if it doesn't come into assessment, how could it be an outcome measure if it's not assessed at baseline, how important are those... B you mentioned early on about being quite brutal I think you said from the surgical approach, but the sort of holistic management of patients, quality of life, activities of daily living, are they worth measuring, are they something that gives you a better picture care or... how do you feel about... do you use them yourselves, would you invest in it? What's your opinion on those two particular aspects? If we take quality of life first of all, is quality of life measure, and we know about the outcomes framework from the Department of Health. Quality of life's one of the key standards, all that sort of depending on what sort of politician you are and what sort of data you want to show off on your Trust. Does quality of life feature heavily in your life for this particular condition to measure, or not, as the case may be?"

D "No purely... we don't have the sort of framework in place at the moment to actually measure that very easily. We've tried, you know, ?? and things, bits and pieces don't work, so... but it's not just, you know, tib post, it's the whole thing, you know, collective... surgery... I know in surgery they use the various tools, which have the quality of life built into it, so that's automatically collected, but it's kind of more difficult for... not more difficult, but we just don't..."

C "Probably... I think realistically in my practice it's time per patient and how I measure... you use the audit... you use the tools available for that. I personally do like the foot and ankle ability measure which is a physiotherapy based scoring system which I think is quite useful. I probably don't use it a lot in NHS practice, purely down to time."

E "So it takes a less... what you're really saying... it's not priority then..."

C "I don't disregard the functional ability so I will sort of push patients into a... I'll compartmentalise them into a treatment based on that so I might take a, I don't want to sort of be too specific, but you'll typically get a patient that's had a fairly rigid flat foot for twenty years that doesn't want surgery and is quite happy just to... with some advice and..."

D "And totally, you're making a quality of life measurement when you're doing the history, you may not be using a formalised..."

E "I was going to say you don't use any objective quality of life measures currently and you wouldn't use in this practice currently?"

D "No."

E "B would you?"

B "I use a sort of... I've got... I use the American AF ??? and I use that as a retrospective tool. I don't do it in the clinic again for time reasons, so I'm following up by group of tib posts at the moment, and surgically functional, and in the clinic, I do make assessment of quality life and activity of daily living, if the patient, well like C said, if they've got stage three fixed disease and they come in and say look actually I can walk to town and back and this doesn't hurt, I put up with it, then I say right this patient's quality of life isn't affected significantly, I'm going to manage you conservatively, because the surgical option is pretty rotten. And if they come in and say my quality of life is awful, I used to be able to walk three miles, I can now only walk twenty feet, my quality of life is appalling, then it's a major factor. So I make an assessment, I don't do a formal staging system."

C "I would agree with that."

E "What about in physiotherapy practice, quality of life, activity of daily living, A, would that feature in your...?"

A "Yeah and I think it should feature and I think, you know, they're all very highly qualified practitioners that are in the room that are saying they're making the judgement, but I do think when someone actually sits and... my background is rheumatology so it's a very different process that you go through, but certainly kind of... I think that with anything that's a long term condition which this condition seems to sit within, I do think we can make a judgement in that three miles into town is enough, but actually that person doesn't feel that that's enough and I think sometimes we do make judgements in clinic due to time that possibly these questionnaires and things like that can give the patient a little bit of time to actually focus and think is this impacting, am I just kind of going along with this practitioner because this person really knows what they're saying, and they're the

professional here so I should agree with them. And I think sometimes it gives everybody that little bit of space just to think what is important to the patient. But the reality is that, you know, they are very time consuming and that's one of the biggest problems with them and I think that's why they're not included in practice."

B "Given the choice you'd have one with every patient. And for every patient given the choice."

D "Oh absolutely, you'd do... and I think the best ones are actually the qualitative questions which you can't possibly do with every patient, or on the quantitative ones, because they actually give you better information, but er..."

E "I suppose for the sake of argument, for the debate here, I mean it's... my area's in diabetes and it features quite a lot, but it wouldn't feature in say in an ulcer classification system, and we're talking about staging the severity, so I guess it's the appropriateness I guess, one assumes, activity of daily living, quality of life would come into an overall assessment, but in terms of classification it may not have a part to play, I mean... for the purpose of the classification staging it wouldn't come in... it comes into your assessment and basic principle it sounds like behind it, but it doesn't sound as if it would come into a staging of severity tool as it were? OK."

B "But as a management tool I think it's useful. So how am I going to progress? Regardless of the staging."

C "And how are my orthoses working for this stage one person? Is he back to running? If not..."

E "Is there anything else that we've now... we've gone through a notion of looking towards consensus, there wasn't a consensus from the questionnaire. It looks like you started off by saying yeah we'll go along with staging, stage one is really based on symptomology, based on pain, particular site of pain, but the degree of severity of pain which is, interesting, you'd take on board with assessment, but really isn't a feature of separating out the staging because if there's no dysfunction, the symptomology will be the key thing at stage one and on x-ray or on imaging it would be a no apparent pathological changes except perhaps some early changes, tenosynovitis, B you mentioned earlier on. Stage two and stage three seems to be crucial here where imaging comes into its own and you've talked about the low end and high end and stage two was all about dysfunction and some of those measures. Stage three you moved into, it sounded like imaging came into its own where you were getting absolutely fixed deformity, you were getting bony changes, you were picking up quite a lot of criteria you mentioned. And then stage four was really the... the really high end of stage four, so stage four, depending on severity really was down to which surgical option may be taken. So the different criteria and assessment you kind of agreed upon were also from that you can infer particular conservative or surgical options and it's the low-

end, high-end criteria you did articulate throughout which, but for sake of a staging classification tool, you wouldn't want to see nine or ten staging, but within those stages there might be some agreed criteria you know fits in low-end, high-end for the sake of management decision making processes. Activities of life and quality of life were important, but didn't fit in and didn't have a part to play in the classification or staging severity. There was no real disagreement of anybody really. You used imaging appropriately and accordingly. You all had different models of care. And the assessment overall tool, in terms of ??? did take on board patient symptoms, but very much sounded like it came to much more objective findings from dysfunction and you're taking on board much more than symptomology towards stage two, three and four. Is that a reasonable summary?"

B "It's a very good summary."

All agree.

E "And I'm just wondering on that if there's anything else you'd like to add."

A " I think just from the non-specialist point of view I think what's interesting, what I've heard, is that actually you've all got a very clear interest in it, and I think it's those patients that go to either the podiatrist, the physio or the orthopaedic surgeon who don't have the interest that I'm sure there's a lot of mismanagement that goes on and that's certainly kind of my experience and how you're going to be able to use this classification to get it out to the people who don't obviously have the interest really, you know and that's where it's..."

E "Absolutely. And that comes across loud and clear doesn't it?"

A "Yeah, you know, that has very strongly come through."

E "F have you anything else you want to add?"

F "Well there's just a couple of comments really. One is around the... we've talked a bit about... going back to the question I had about... do you think... is there anything else that you include in your assessment that might not feature in the traditional classification? I mean there's a couple of things, because B was talking about both plantar ligament involvement and comorbidities, and you mentioned comorbidities as well, which actually doesn't really fit into the classification system that we currently use, but it's... you know, what's your opinions on whether, you know, there are things that could be added to it that are common features that you now consider, that perhaps you didn't, or haven't been considered previously?"

D "What do you mean, sort of exclude, but we're actually bringing exclusions in and... but don't forget to exclude this..."

E "I think that was a key point wasn't it, when B said about the list of... when stage three and stage four was very much more in that, the rearfoot, wasn't it, and how that might not even involve posterior tibial tendon in the first instance, so I don't know, but by that clear history taking, you said D that you could pick up on that, so he was saying about those added bits and assessments, stage three and stage four, you know, it makes sure it's not x,y and z and I think that was..."

C "But I think... I mean I think that is essential, but I think you would have done that in your assessment. I think you... my diagnosis is it's not that, it's not that, around this area, it's not that, it's not that, it's not that, I think it's that, let's confirm it, confirm it..."

D "As A was saying, it's when it's not someone who's used to dealing with it, sees them, that we need something more, you know, if that's going to be used, or if it is used, the classification table, by someone who isn't... maybe has got a triage type of clinic, or a general practitioner, is there more information that could go in there to help direct them, because when we had one recently, that had been floating around for months and months and being treated by... I think it was being treated as a tib post problem, eventually ended with a diagnosis in the end was... it was Charcot."

A "How long is your assessment time usually? How long do you get for an assessment on...?"

D "We get half an hour for a new patient."

A "And how long do you usually get to see a new patient?"

B "Five minutes."

D "Five minutes!"

A "Yeah, you see..."

C "That's incredible."

A "...and that's the other thing, you know, whereas as a physio and a new patient, we range from thirty minutes... some places are very lucky and get an hour so... you know, that's the other component of this, is the time you have to explore the foot, in you know, to explore that hindfoot, kind of whether there is any stiffness or not, subtalar, all of that, you know, that's hugely variable and that's where this classification's going to be really helpful."

F "And the other part of that is about, in your opinion, a) is there a need? but b) where is that need, is it amongst the people that see this condition or is it amongst the people that aren't perhaps

specialists in this area? I mean I... we haven't really explored that in any detail, but I'm just interested in what you..."

D "I think... what I think is lacking is, for example, is in the sort of general practice, you know, whether it be doctors or podiatry or physio because there's... the awareness probably isn't out there. Look at Map of Medicine, it's not even in there, only as a possible diff diagnosis for plantar fasciitis, and I think it needs to be, you know, it needs to be out there more... for people to be more aware of it and what to do with it, than it is now. I'm not so concerned when it gets into the specialist clinics, because in there, you know, most people will be aware of it and what to do, but it's... the patients who are outside there, that originally, you know, where you... as I say, you need to get in early so that they don't progress hopefully."

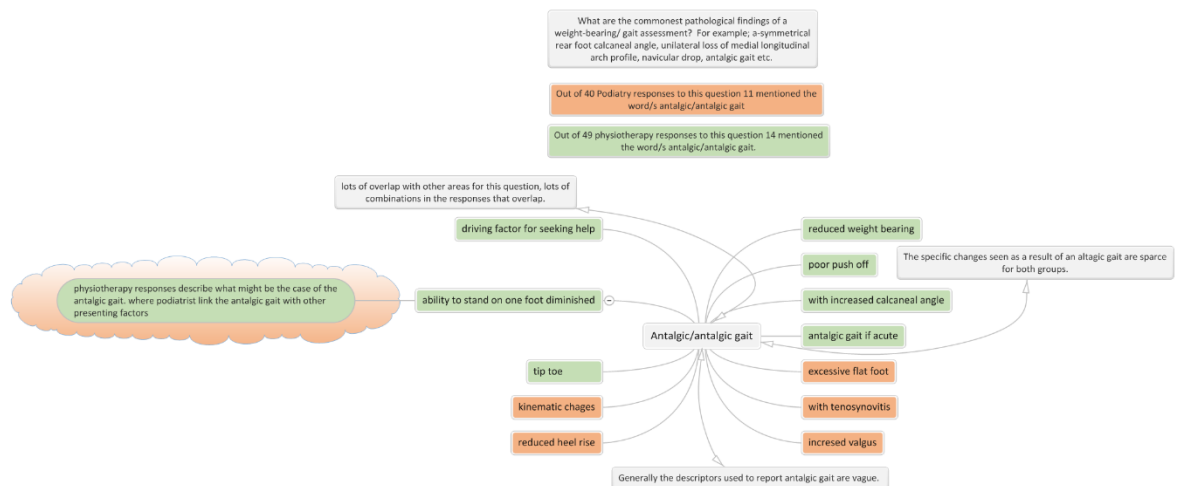
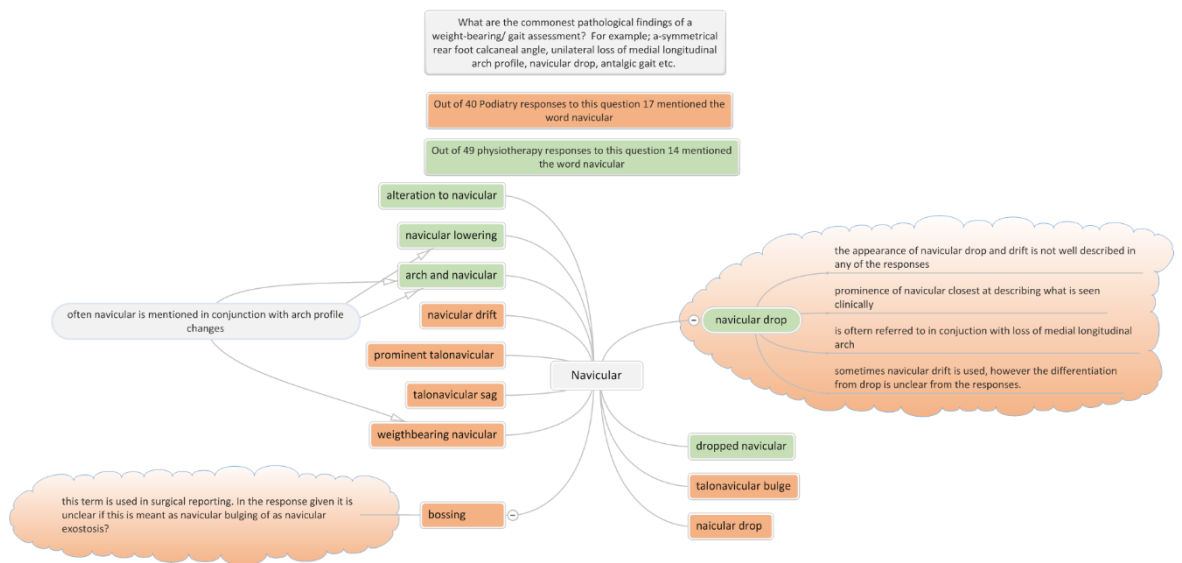
E "That's almost... you're almost spilling into aren't you, into... dare I say, you're almost spilling into a referral pathway aren't you? In terms of... you've moved away from the classification of the condition of saying here's agreement of stage one and here's what should be happening, and which is a... a broader management debate about who should be referred to first and all the different... In the same we took an eternity over our new footcare pathway that we've sent to every single Chief Exec and every hospital throughout England, with our one side of A4 pathway and it sounds like you're spilling into the management issues, best practice, more... away from the classification."

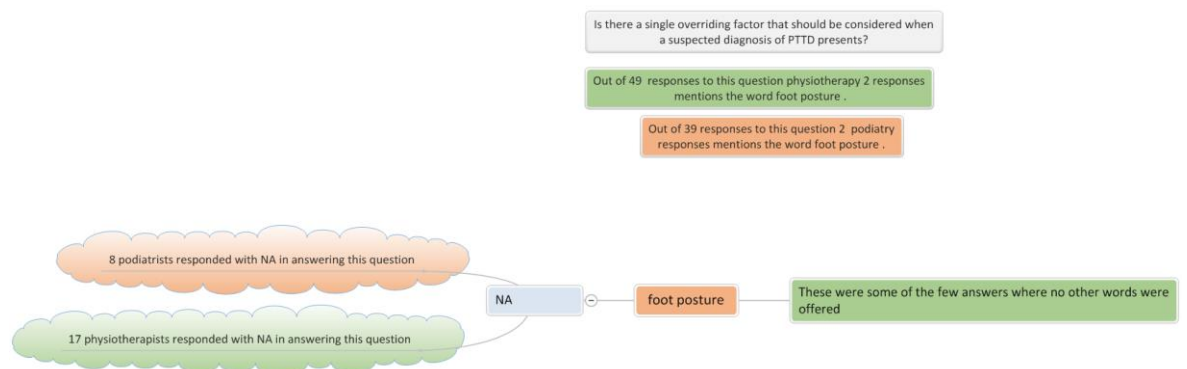
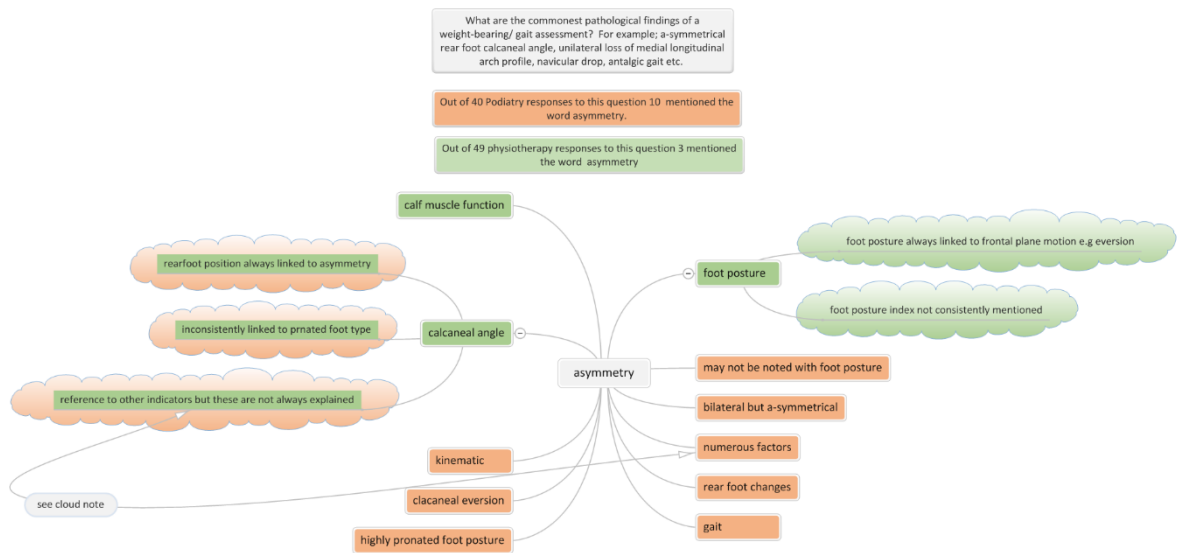
F "Yeah, I mean I suppose just listening to the conversations round the table, you know, we're all signed up for the fact that yes it needs to be an early diagnosis, yes best prognosis if it's early diagnosis at stage one and can, you know, can be managed quite happily, conservatively, so if that's the case should we be setting the scene for actually... for non-specialists to be able to identify at that stage, rather than coming into your clinics as a... you know, late stage one, stage two, whatever, stage three, whatever? And is that where the need is or do we need to beef up what is already in existence which is primarily for people who already know about the condition?"

B "Yeah, a couple of things from that, I think there's a widespread, as D said, a widespread ignorance about this condition. I think you'll find in this room at the moment are six of the ten people in S who know anything about this condition at all. There aren't many people, there's S & D and one or two other people, there aren't many people, so the widespread... almost all of my orthopaedic colleagues and then I guess podiatrists and then across the entire spectrum... so a lot of people won't know much about it. In fact there's probably more podiatrists who know something about this, than there are orthopaedic surgeons, I guarantee you. So I think it... there needs to be a dissemination of information that this is a true pathological condition that needs to be recognised, it needs to be diagnosed early, and I think that's probably a really important thing from this. And so secondly, the variability regarding staging criteria, it seems that we all actually agreed on what belongs in each of the four stages. There is a slight variation, but we're pretty honed down on it.

As soon as you disseminate this to GPs, orthopaedic surgeons, podiatrists, physiotherapists, everyone in the spectrum, you will get a massive variability, you'll never be able to hone it down, which is why rather than having nine grades, like we're thinking about nine grades quite clearly, keep it simple for them, mild, moderate and severe, which is always a good way to think about things. So I think that you will have massive variability amongst the general population, but as soon as you get to sub-specialists like all of us here, you're going to have real conformity and I think that you've got almost conformity of views here, even though we're all different specialties."

12.3 Mind Maps illustrating open ended context codes for each questions

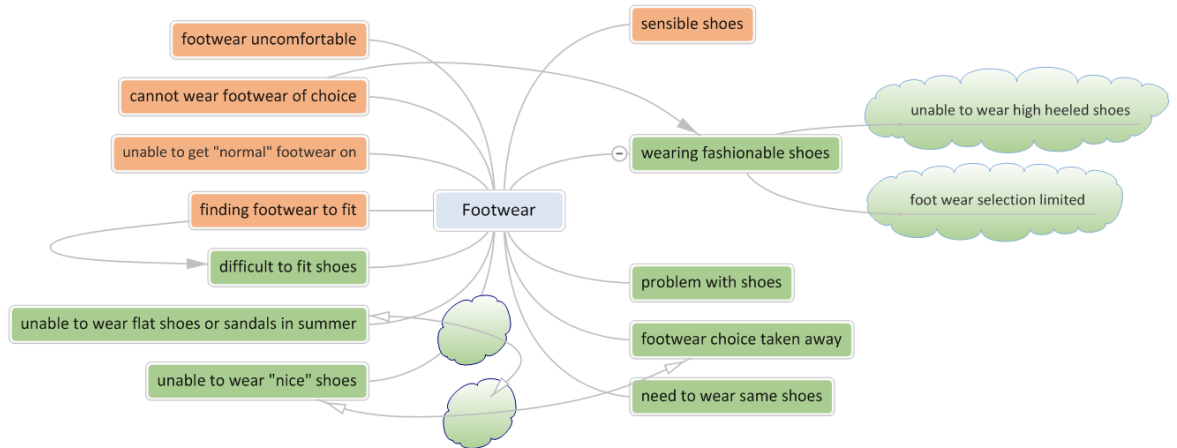




What are the most common restrictions in activities of daily living reported by patients ?

Out of 49 physiotherapy responses to this question 9 mentioned the word footwear.

Out of 39 podiatry responses to this question 4 mentioned the word footwear.

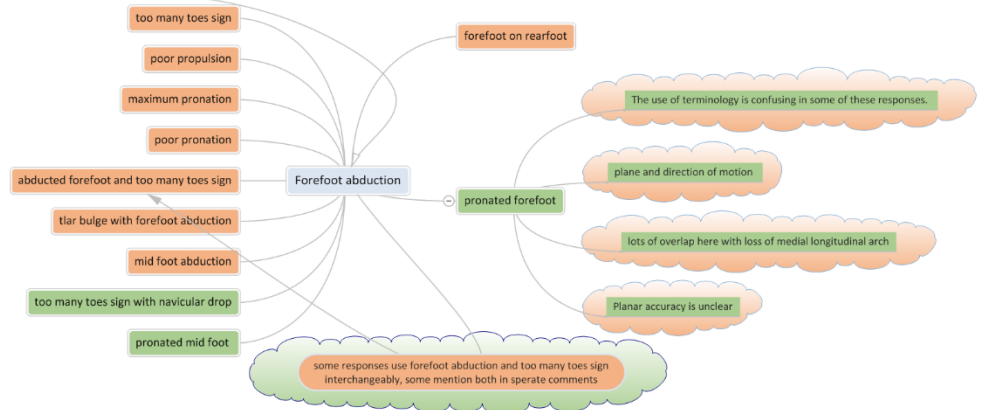


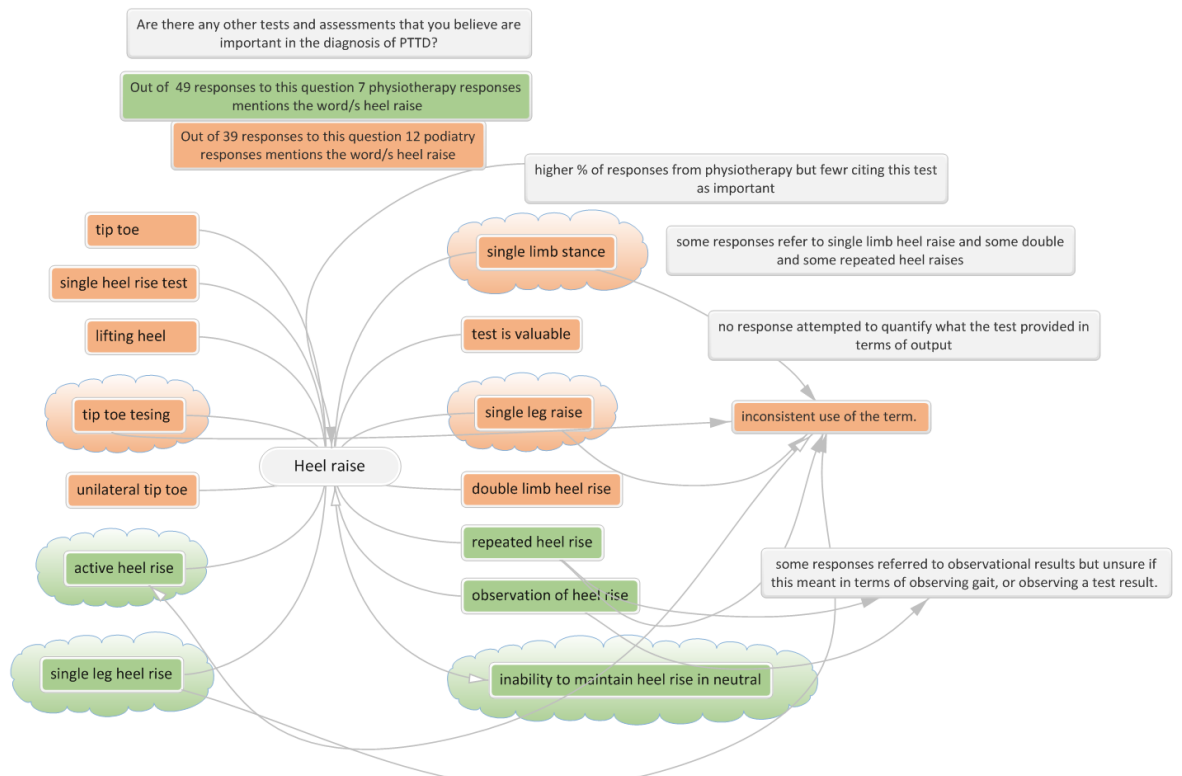
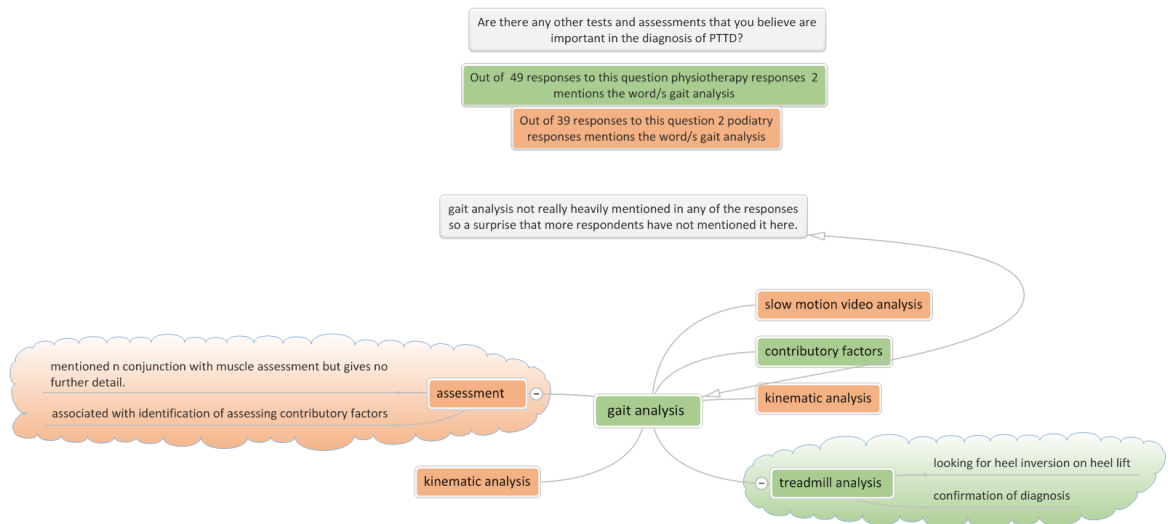
What are the commonest pathological findings of a weight-bearing/ gait assessment? For example: a-symmetrical rear foot calcaneal angle, unilateral loss of medial longitudinal arch profile, navicular drop, antalgic gait etc.

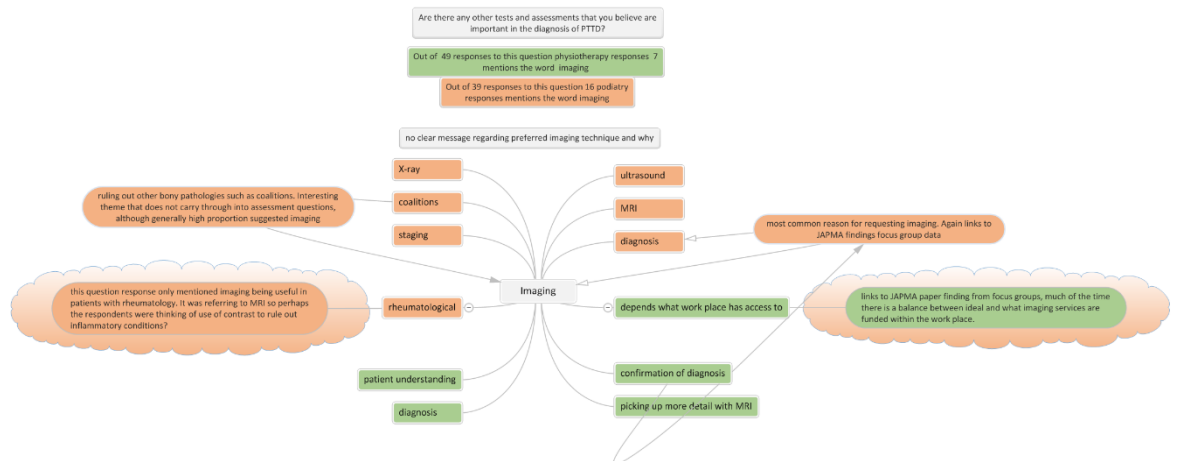
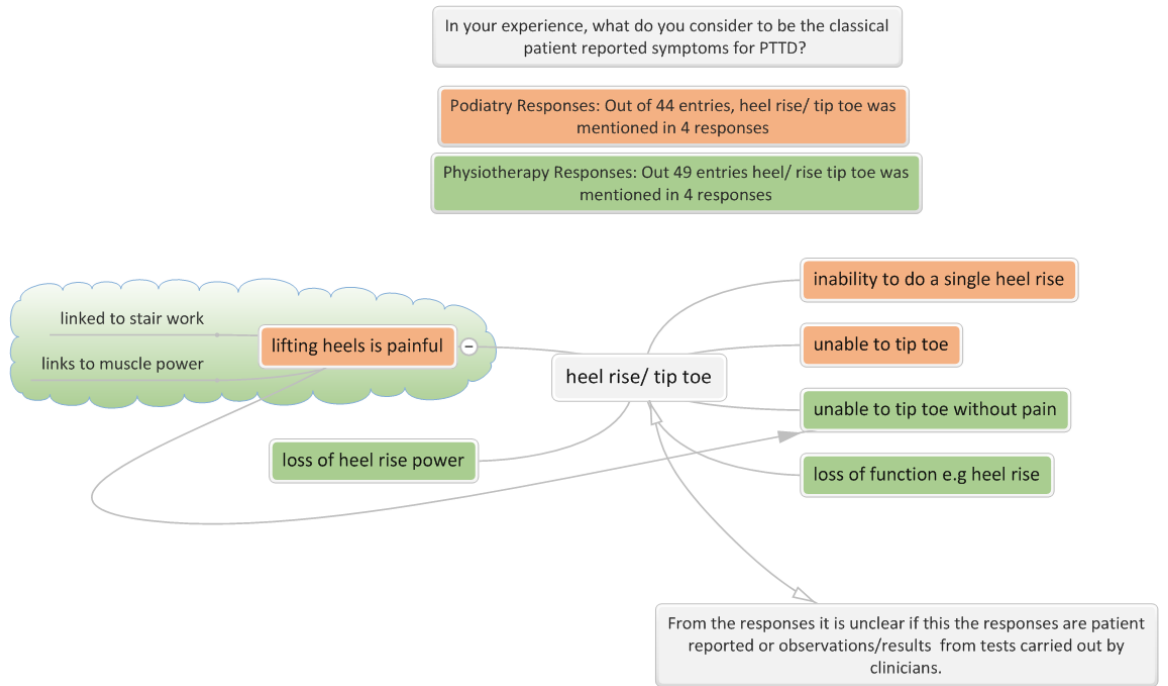
Out of 40 Podiatry responses to this question 19 mentioned the words lowered forefoot abduction

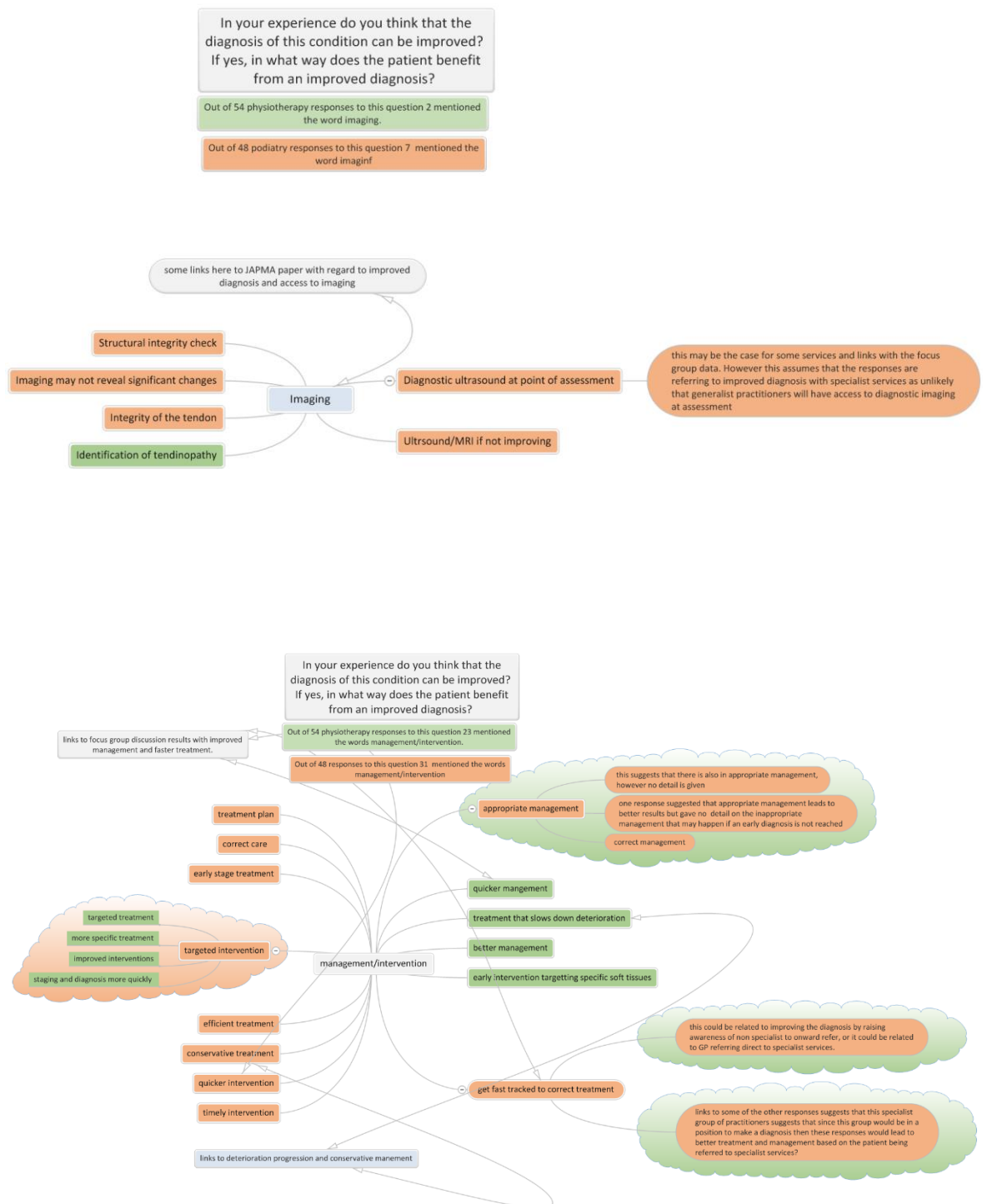
Out of 49 physiotherapy responses to this question 16 mentioned the words forefoot abduction

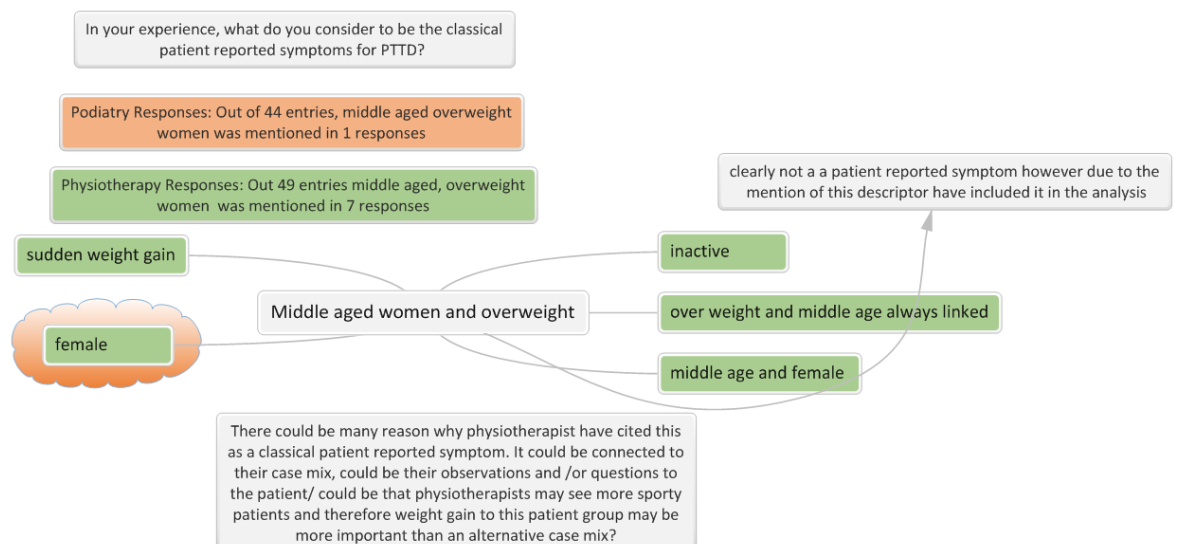
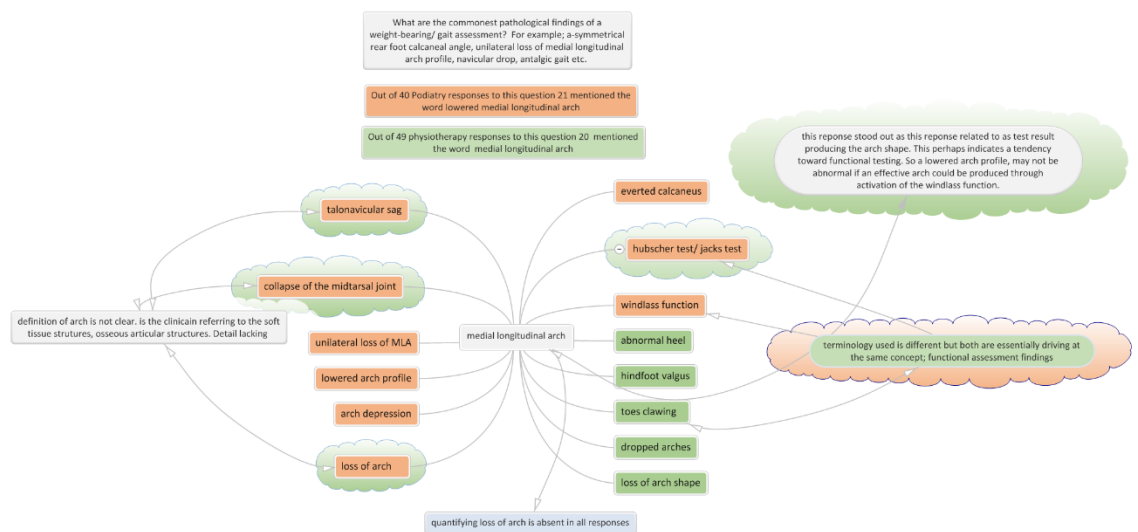
lots of links to other key words, antalgic gait, gait changes, and the pain responses to Q.5

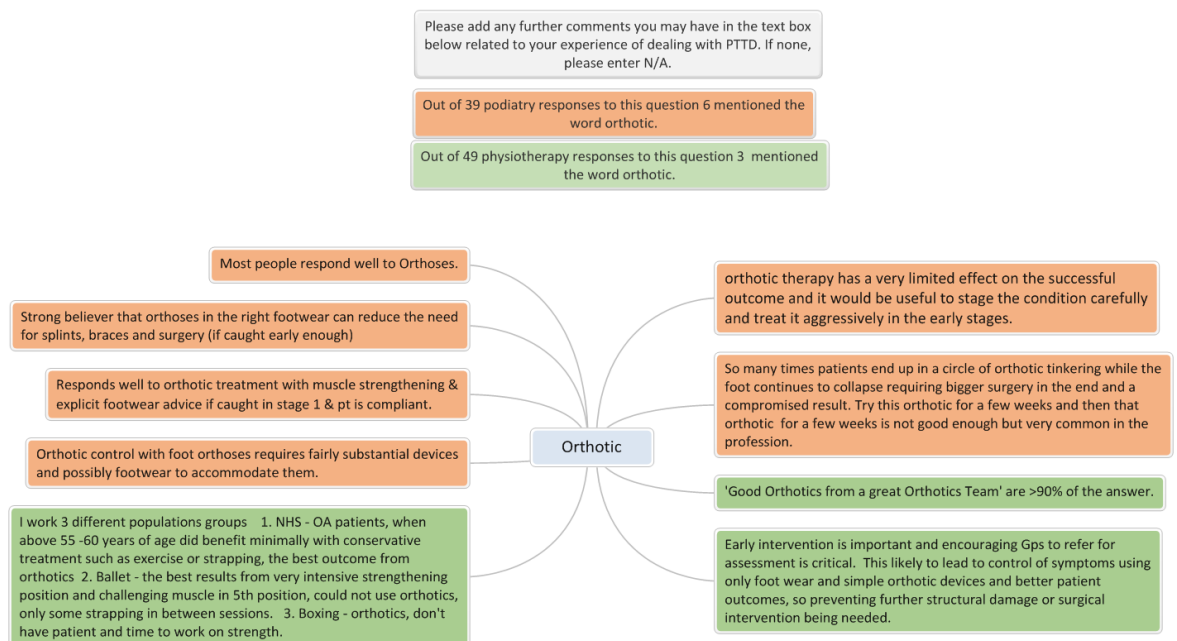
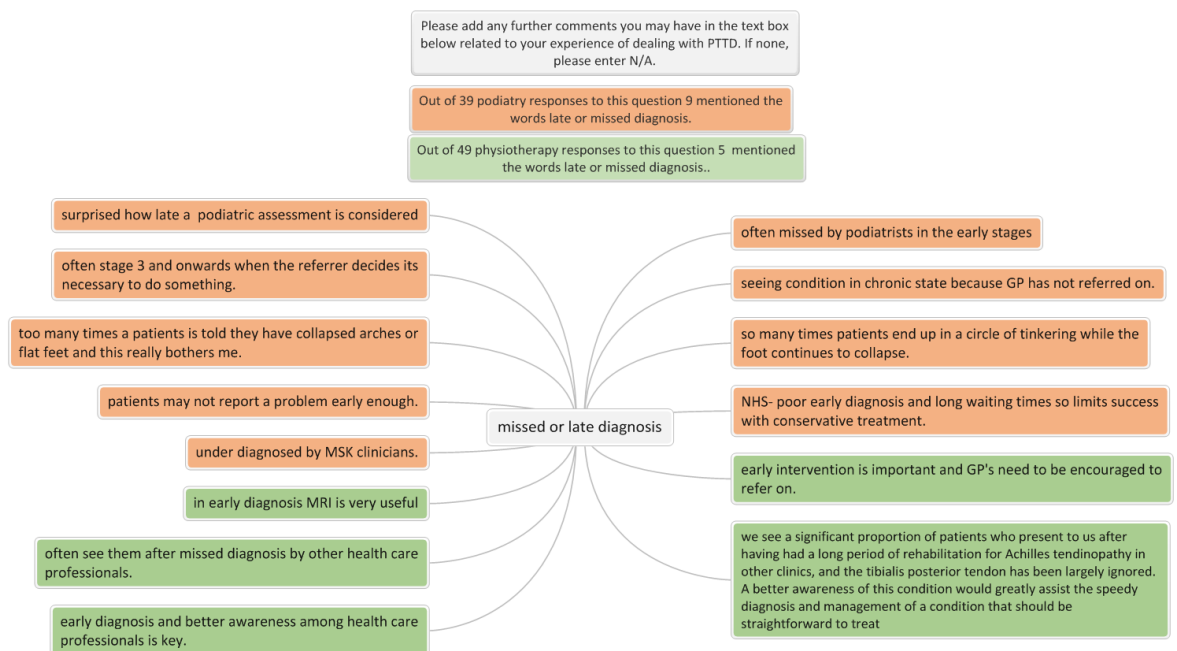








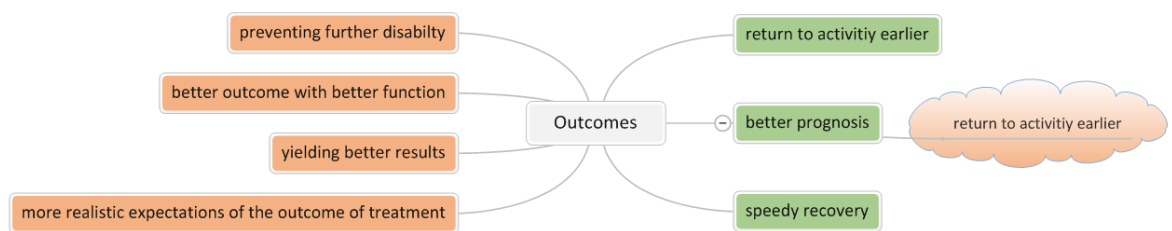




In your experience do you think that the diagnosis of this condition can be improved?
If yes, in what way does the patient benefit from an improved diagnosis?

Out of 54 physiotherapy responses to this question 3 mentioned the word outcomes.

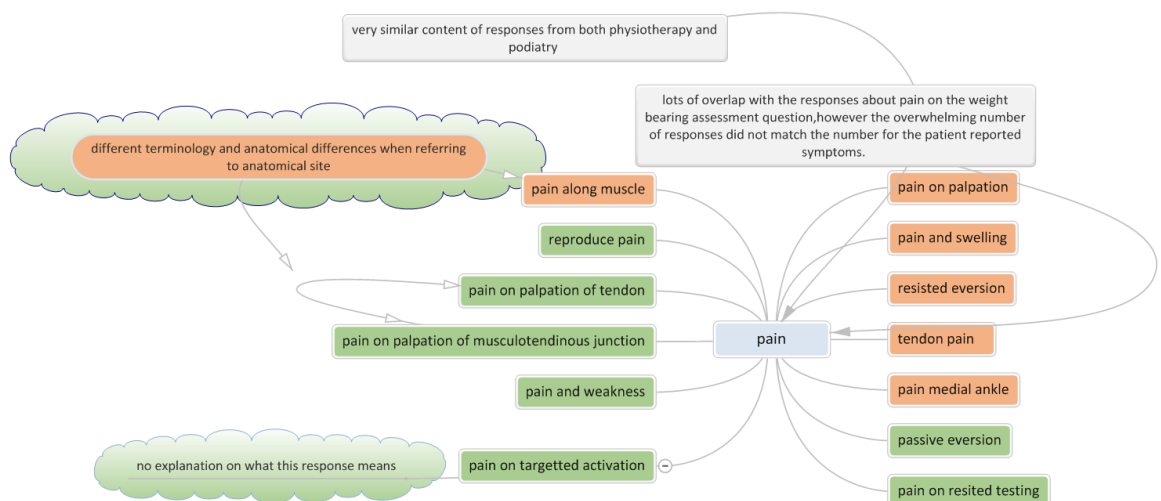
Out of 48 responses to this question 10 mentioned the word outcomes.

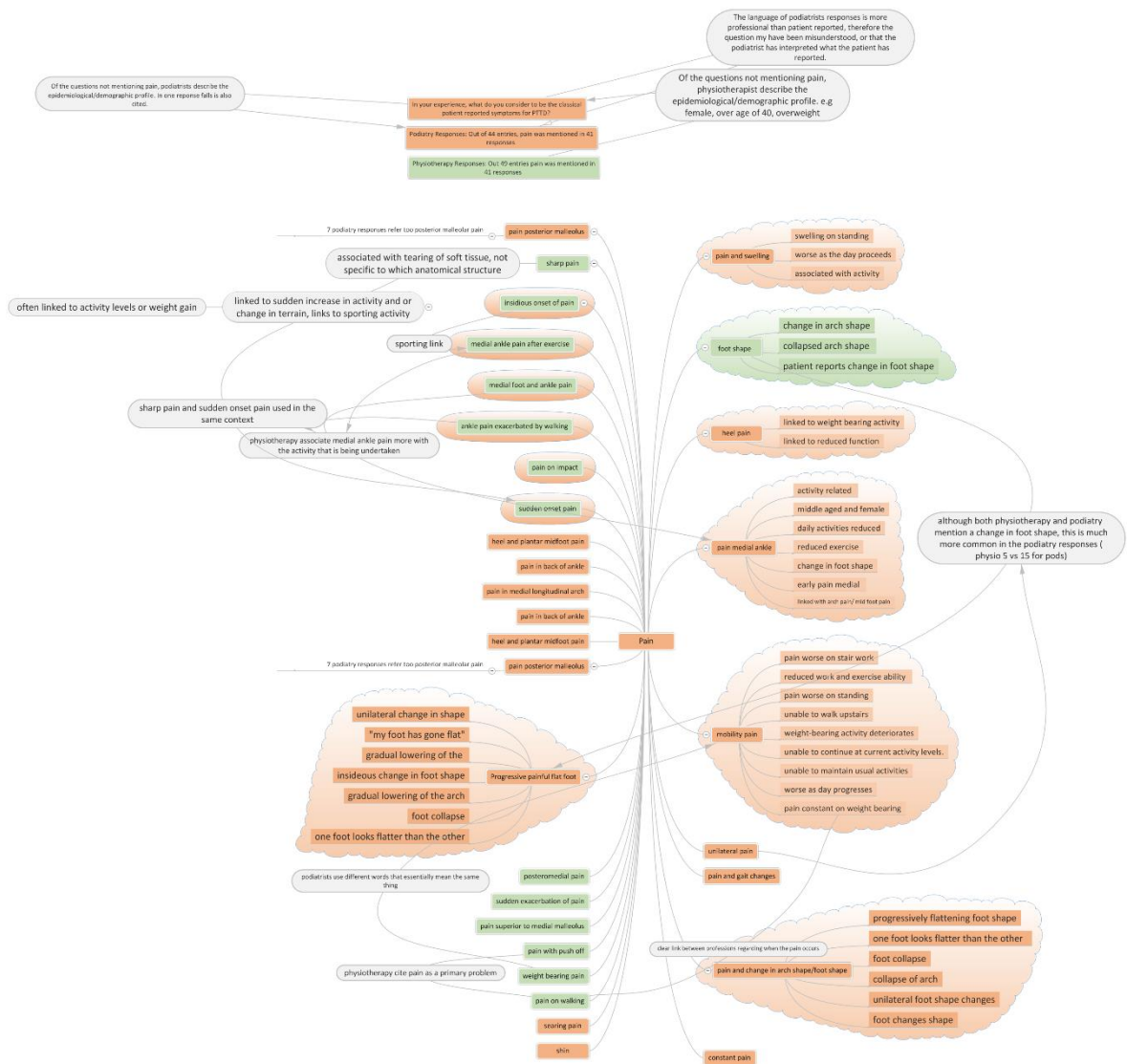


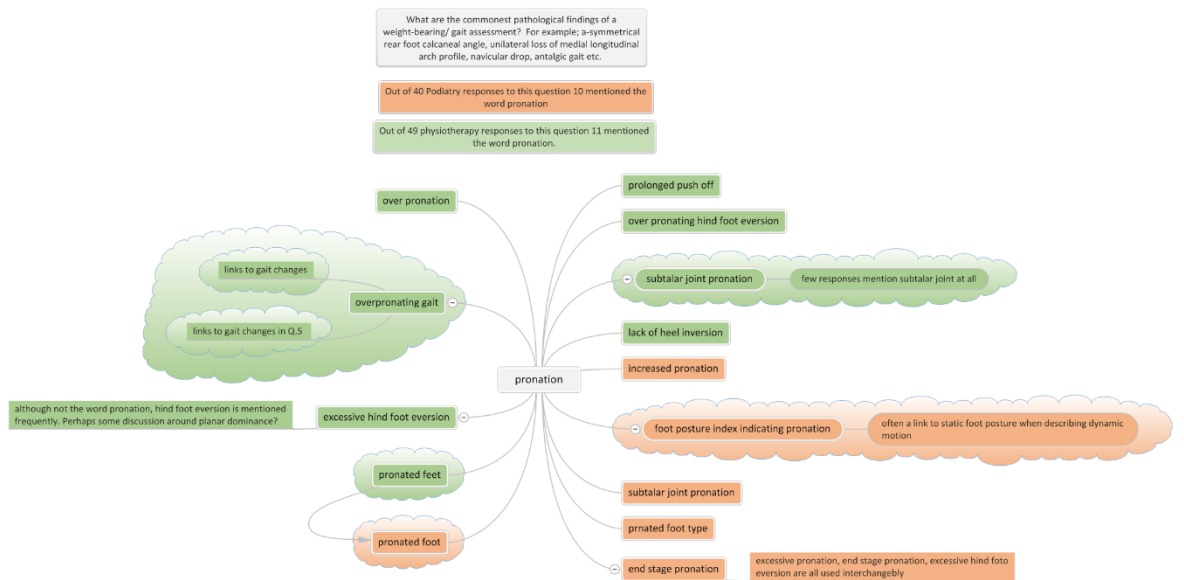
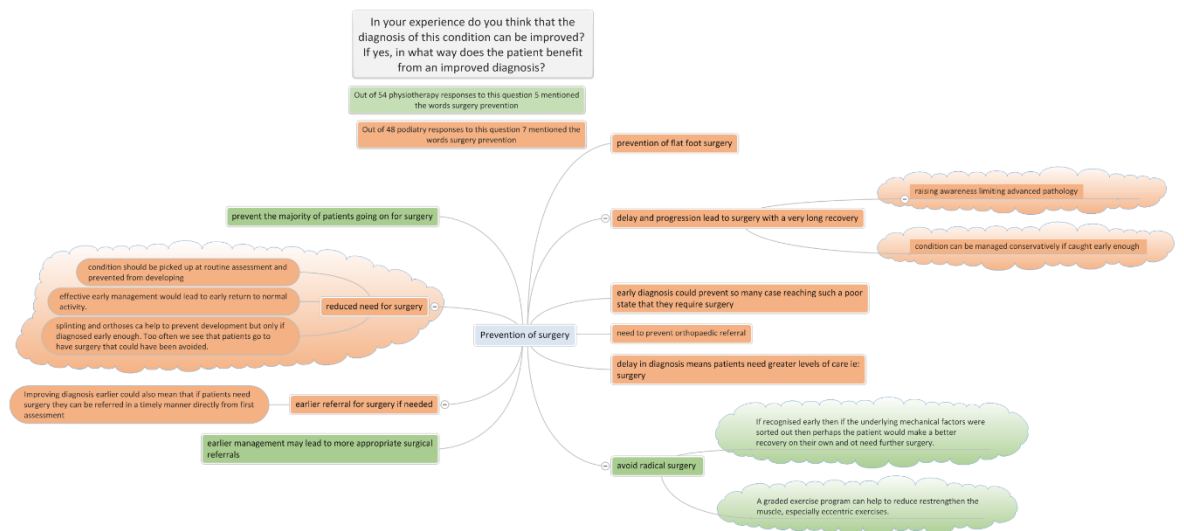
What would you consider to be the main findings of a non-weight bearing assessment? For example, limited subtalar motion, abnormal manual muscle testing, pain on palpation etc.

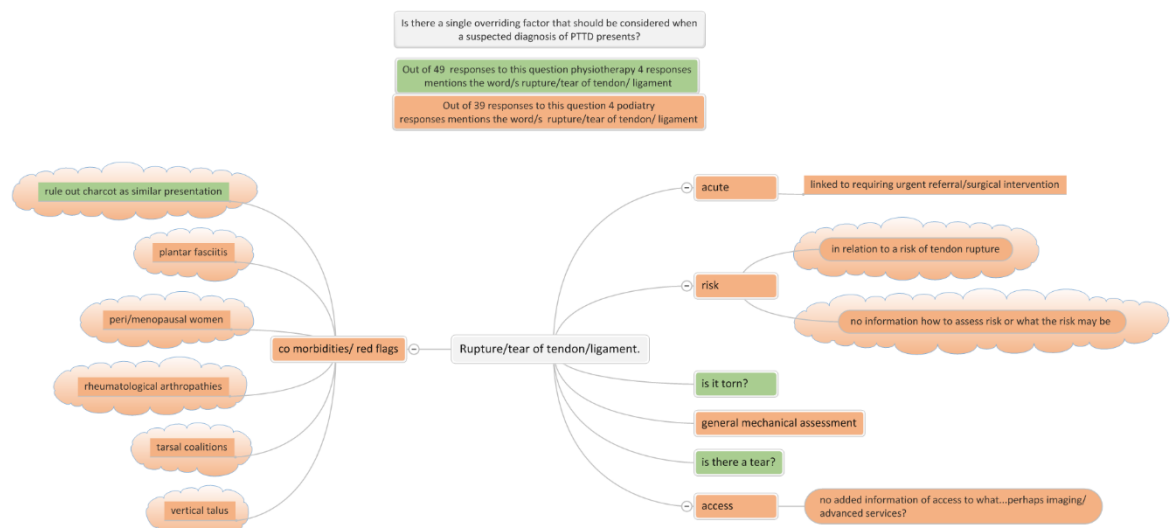
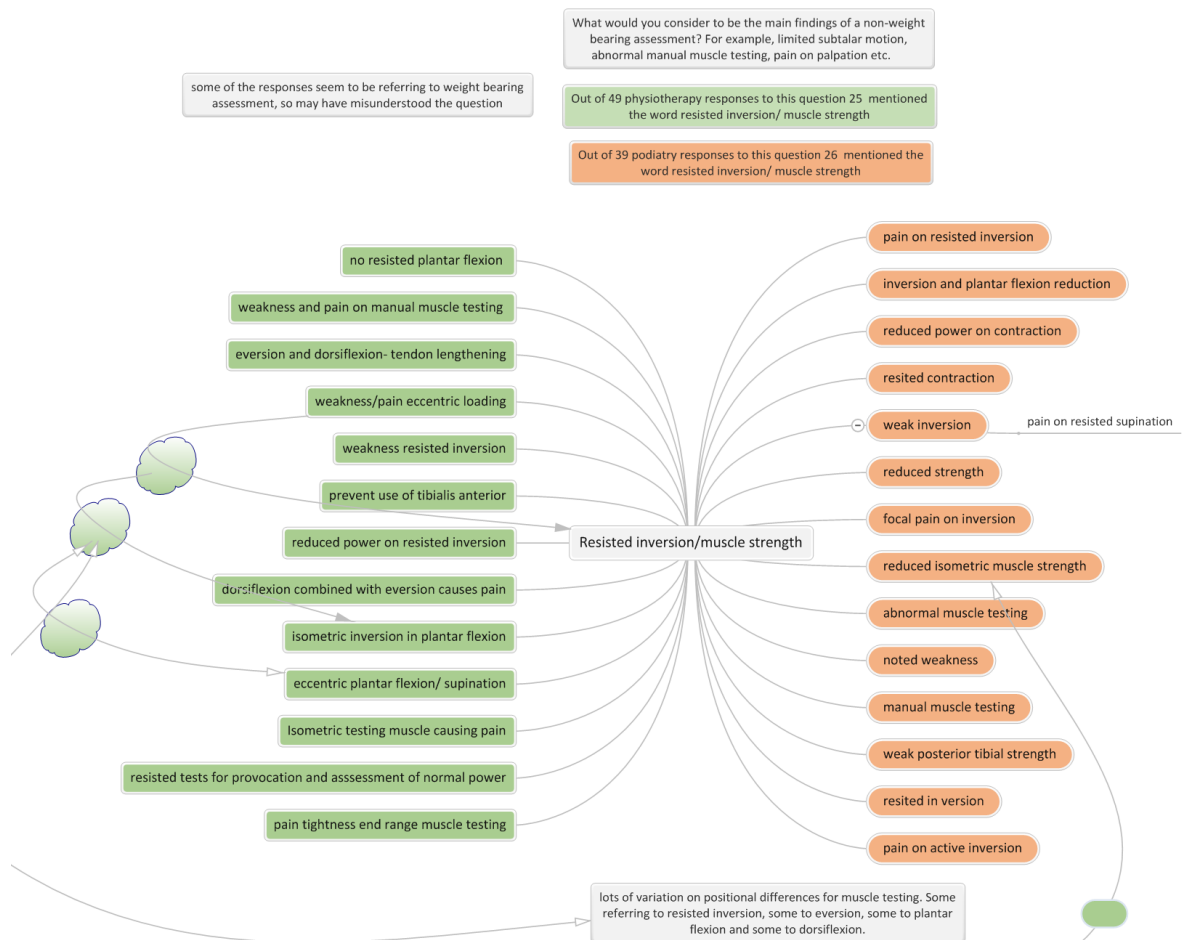
Out of 49 physiotherapy responses to this question 37 mentioned the word pain.

Out of 39 podiatry responses to this question 32 mentioned the word pain.





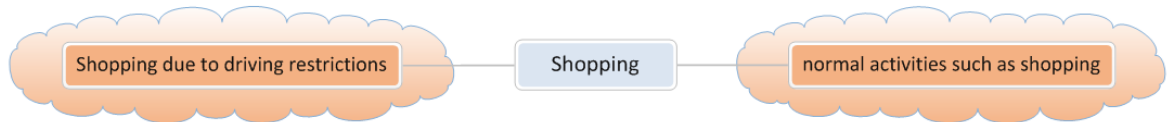




What are the most common restrictions in activities of daily living reported by patients ?

Out of 39 podiatry responses to this question 3 mentioned the word shopping.

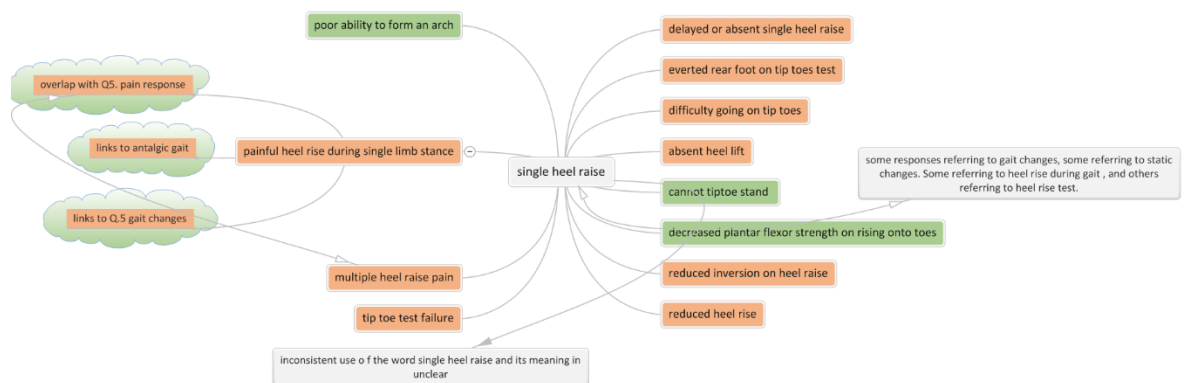
Out of 49 physiotherapy responses to this question 0 mentioned the word shopping.

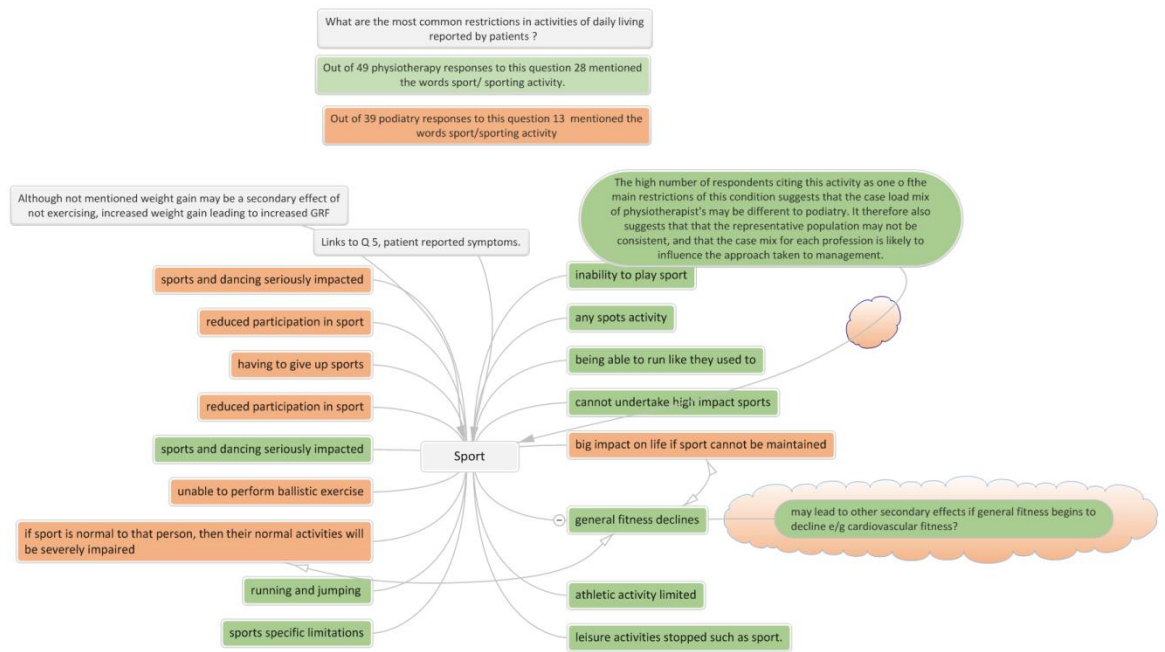


What are the commonest pathological findings of a weight-bearing/ gait assessment? For example; a-symmetrical rear foot calcaneal angle, unilateral loss of medial longitudinal arch profile, navicular drop, antalgic gait etc.

Out of 40 Podiatry responses to this question 19 mentioned the words single heel raise

Out of 49 physiotherapy responses to this question 9 mentioned the words single heel raise

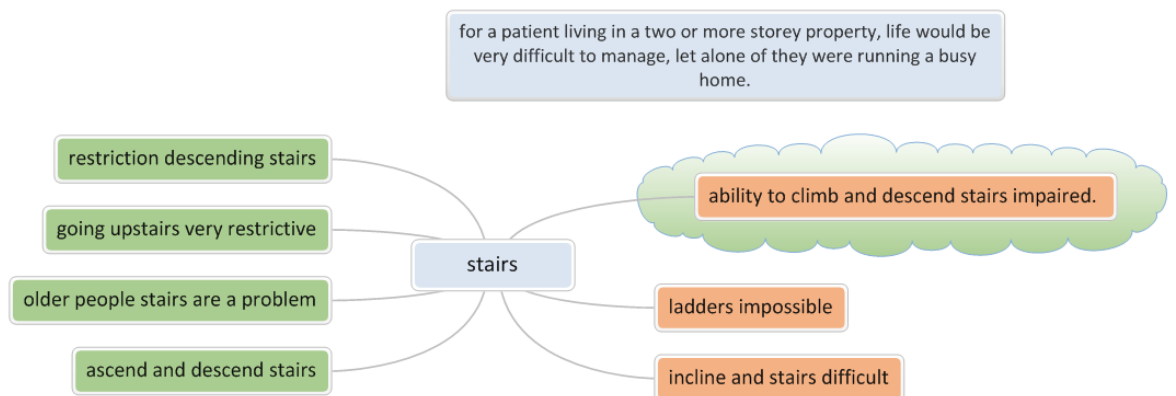


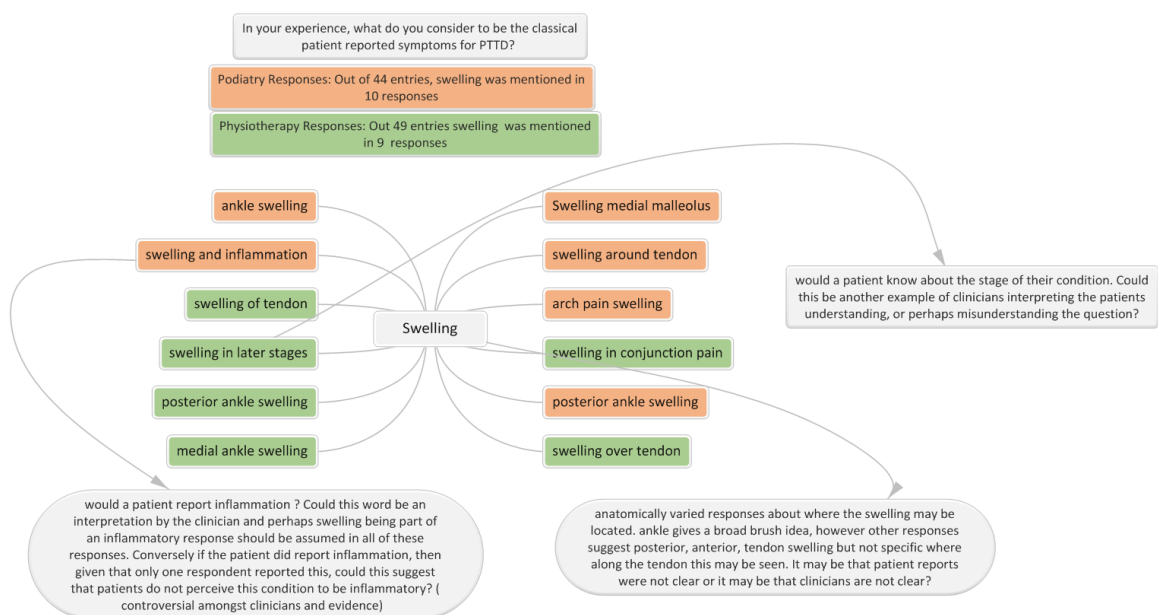
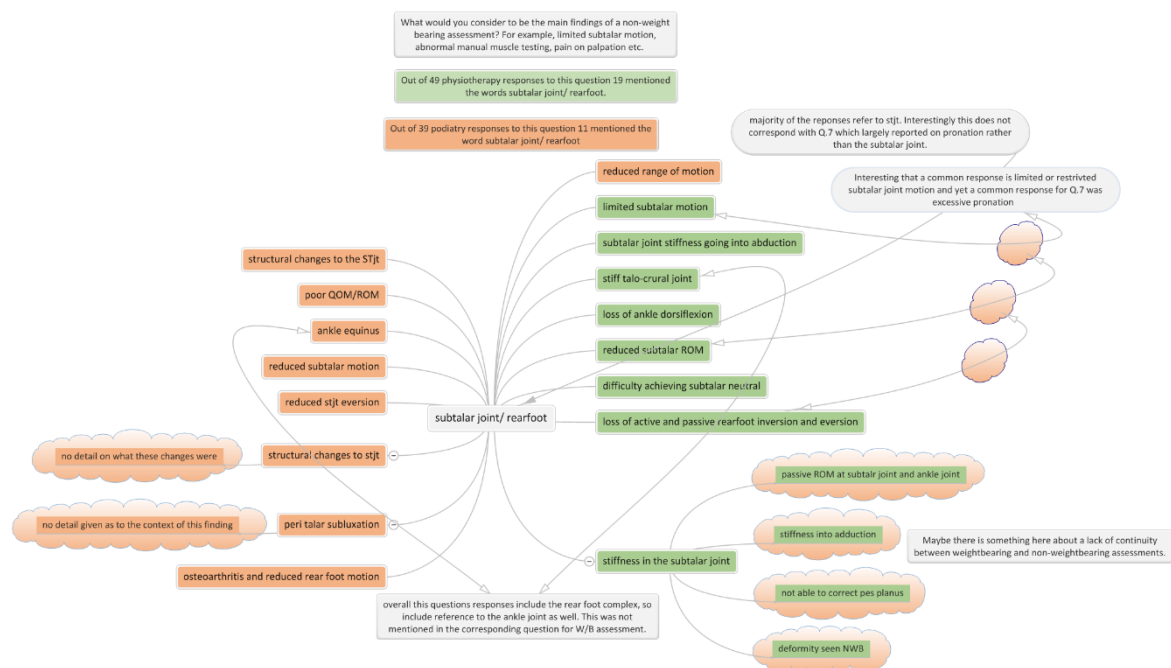


What are the most common restrictions in activities of daily living reported by patients ?

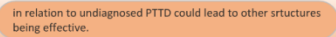
Out of 49 physiotherapy responses to this question 10 mentioned the word stairs.

Out of 39 podiatry responses to this question 3 mentioned the word stairs.

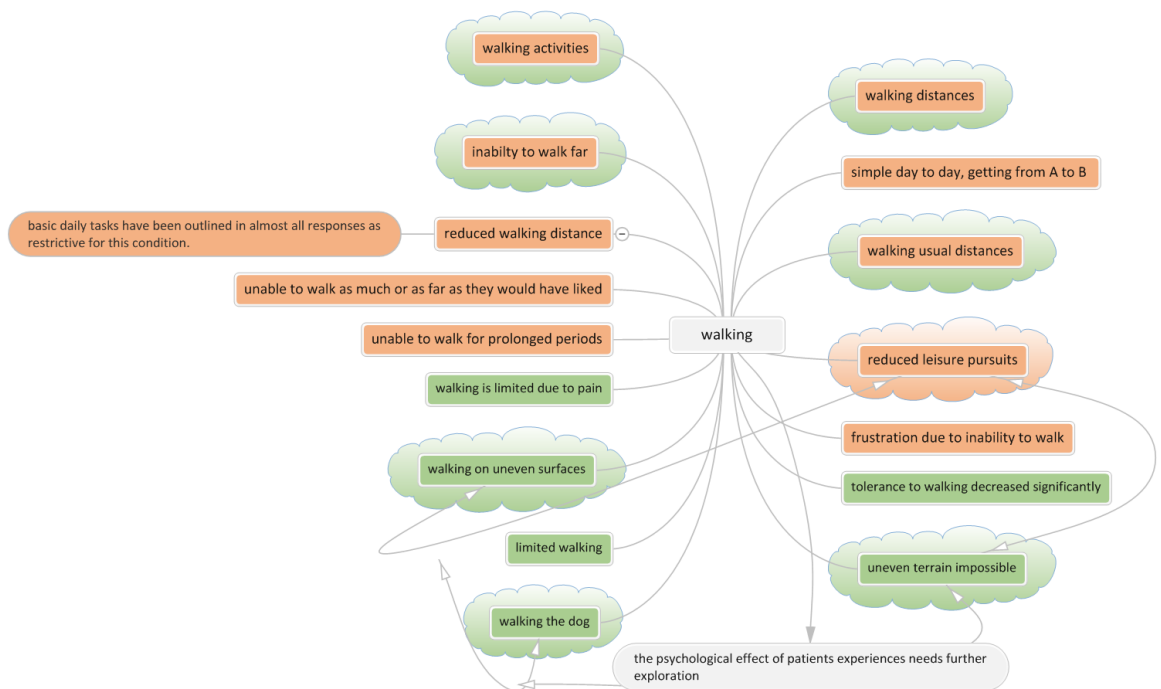


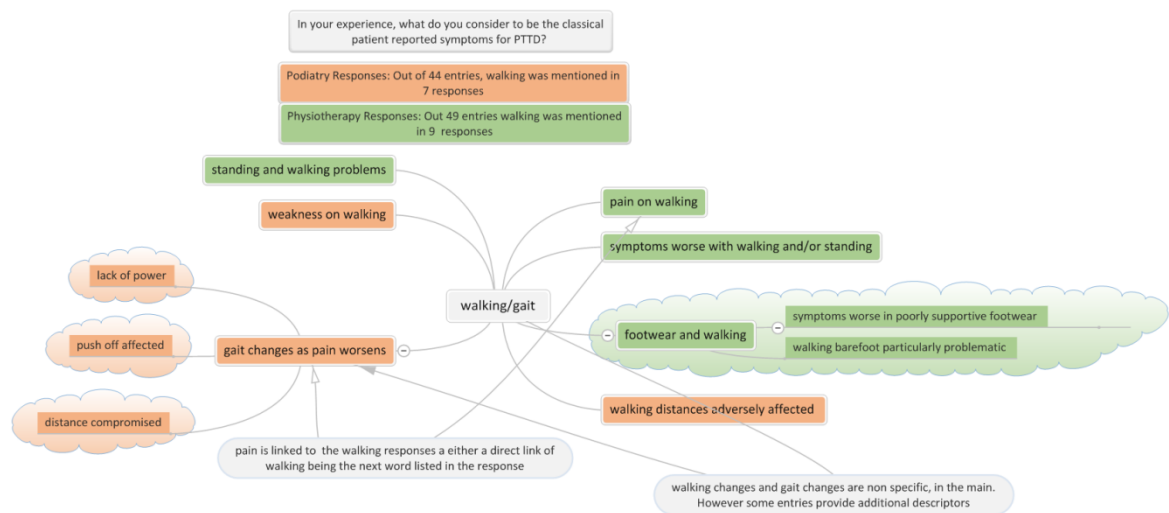


Out of 39 responses to this question 4 podiatry responses mentions the word unilateral.



Out of 39 podiatry responses to this question 25 mentioned the word walking





12.4 Ethical Approval/ Favourable Opinion



National Research Ethics Service

NRES Committee West Midlands - Staffordshire

HRA NRES Centre Manchester
3rd Floor
Barlow House
4 Minshull Street
Manchester
M1 3DZ

Telephone: 0161 625 7815
Facsimile: 0161 625 7299

08 August 2012

Professor Nachiappan Chockalingam
Staffordshire University
Faculty of Health
Leek Road
Stoke-On-Trent
ST4 2DF

Dear Professor Chockalingam

Study title: Posterior tibial tendon dysfunction and its biomechanical effects on the lower extremity
IRAS Project Number: 98558
REC reference: 12/WM/0099

Thank you for your email of 23 July 2012, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Vice-Chair.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

A Research Ethics Committee established by the Health Research Authority

12.5 GCP training certificate

THIS IS TO CERTIFY THAT
BEV DURANT
HAS COMPLETED GCP TRAINING ON THE 16TH NOVEMBER 2012
GCP TRAINER: LOUISE PHILLIPS-DARBY

SIGNATURE: *Louise Phillips-Darby* DATE: 19TH NOVEMBER 2012

R&D AUTHORISATION: Dr. Darren Clement

Signature: 

Date: 19th November 2012

12.6 Staffordshire University Ethical Approval

12.7 Research Passport



Faculty of Health

Staffordshire University
Blackheath Lane
Stafford ST18 0AD
United Kingdom

+44 (0) 1785 353766 (Enquiries)
+44 (0) 1785 353673 (fax)
www.staffs.ac.uk

To whom it may concern

Application for Independent Peer Review Approval

Researcher: Beverley Durrant

Study Title: The effect of Posterior Tibial Tendon Dysfunction on the Biomechanical Characteristics of the lower extremity

I can confirm that Staffordshire University supports this research project proposal being put forward by the above research project applicant, and that the University is willing to act as sponsor of the project if it received LREC approval.

Our support for this project takes account of the outcome of an independent peer review of its scientific merit undertaking within the University.

I can also confirm that the University has generic indemnity/insurance arrangements in place as stated on the attachment to this letter, that arrangements will be in place before the study starts for the research team to access resources and support to deliver the research as proposed, that arrangements to allocate responsibilities for the management, monitoring and reporting of the research will be in place before the research starts and that the duties of sponsors set out in the NHS Research Governance Framework for Health and Social Care will be undertaken in relation to this research.

A handwritten signature in blue ink, appearing to read 'Jim Radcliffe'.

Dr Jim Radcliffe
Chair,
University Academic Ethics Sub-Committee

University Hospital of North Staffordshire

NHS Trust

RESEARCH AND DEVELOPMENT DEPARTMENT

Windsor House Annex
223 Princess Road
Hartshill
Stoke on Trent
Staffordshire
ST4 7JW

Tel: 01782 554334
Fax: 01782 554610

Our Ref: DC/hr

07 November 2012

Mrs Beverley Durrant
67 Cornhill Gardens
Polegate
East Sussex

Dear Mrs Durrant

Letter of access for research

Posterior tibial tendon dysfunction and its biomechanical effects

This letter confirms your right of access to conduct research through University Hospital of North Staffordshire NHS Trust for the purpose and on the terms and conditions set out below. This right of access commences on 07 November 2012 and ends on 31 January 2013 unless terminated earlier in accordance with the clauses below.

You have a right of access to conduct such research as confirmed in writing in the letter of permission for research from this NHS organisation. Please note that you cannot start the research until the Principal Investigator for the research project has received a letter from us giving permission to conduct the project.

The information supplied about your role in research at University Hospital of North Staffordshire NHS Trust has been reviewed and you do not require an honorary research contract with this NHS organisation. We are satisfied that such pre-engagement checks as we consider necessary have been carried out.

You are considered to be a legal visitor to University Hospital of North Staffordshire NHS Trust premises. You are not entitled to any form of payment or access to other benefits provided by this NHS organisation to employees and this letter does not give rise to any other relationship between you and this NHS organisation, in particular that of an employee.

While undertaking research through University Hospital of North Staffordshire NHS Trust, you will remain accountable to your Employer University of Brighton but you are required to follow the reasonable instructions of Mr Robin Rees & Professor

L201 - Example letter of access for university researchers who do not require an honorary research contract

Version 2.2, September 2012

Research in the NHS, HR Good Practice Resource Pack

Page 1 of 3

12.8 R&D Approval



University Hospital of North Staffordshire **NHS**
NHS Trust

RESEARCH AND DEVELOPMENT DEPARTMENT

Windsor House Annexe

223 Princes Road

Hartshill

Stoke-on-Trent

ST4 7JW

Telephone: 01782 554334

Fax: 01782 554610

Email: Darren.Clement@uhns.nhs.uk
research.governance@uhns.nhs.uk

Ref: DC/hr

07 November 2012

Professor Paula Richards
Consultant Musculoskeletal Radiologist
University Hospital of North Staffordshire
Newcastle Road
Stoke-on-Trent
ST4 8QG

Dear Professor Richards

Re: The effect of Posterior Tibial Tendon Dysfunction (PTTD) and its biomechanical effects on the lower extremity

Chief Investigator: Professor Nachiappan Chockalingam

Sponsor: Staffordshire University

I can confirm that the above project has been given NHS Permission for Research by the Research & Development Department for the University Hospital of North Staffordshire NHS Trust and the details entered on to the R&D database.

I note that this research project has been approved by NRES Committee West Midlands – Staffordshire reference 12/WM/0099

NHS permission for the above research has been granted on the basis described in the application form, protocol and supporting documentation. The documents reviewed were:

Document	Version Number	Date
Protocol	1	04 February 2012
Participant Invitation Letter	1	17 March 2012
Participant Invitation Letter: Medical Records only	1	17 March 2012
Participant Consent Form: Experimental Group	2	05 June 2012
Participant Information Sheet: Experimental Group Medical Records	2	05 June 2012

REGA ID: NCT01541171; UCRN ID: NCT01541171; NCT01541171; NCT01541171

12.9 Data Collection Check List

Data Collection Check List

1. Create/ open data collection for the session in Nexus
2. Create a folder for the pressure plate in Tekscan.
3. Calibrate Vicon; wand and frame.
4. Zero force plates
5. Set up timing gait cameras
6. Check Basler camera is working in Vicon
7. Participant arrives
8. PIS. Go through the procedure and explain about the MRI situation. Ask patient to complete their name and address and telephone number. Place in envelope and code the envelope with the code is known (see below). Explain that they will be contacted to have an MRI. Check contra indications to MRI.
9. Consent.
10. If participant is in the experimental group then ask to complete the foot posture and disability index.
11. Take height and weight
12. Foot posture Index (use the result to derive the code for the participant). Mark on data sheet participant code.
13. Carry out weight bearing assessments as per data collection sheet. Mark on data sheet participant code.
14. Calibrate walkway
15. Mark up participant with markers
16. Static calibration (run pipeline and check marker placement, replace as necessary and re calibrate) left hand force plate in anatomical position.
17. Carry out single heel rise test on the force plate using finger tip test

18. Then collect 3 trials of walking gait and 3 trials of pressure data. Follow protocol below.
- a. Check synch parameters in walk way
 - b. Go to Vicon and auto capture settings turn on remote trigger start stop and then arm.
 - c. Ensure all files are named the same as for the walkway.
 - d. File for walkway 1 will be W, file for force plate will be F. Eg. Participant 1 for the control group with a pronated foot posture would be 1cW1 or participant for experimental with neutral foot posture would be 1aW1.
 - e. Ensure the calibration walkway file has the same name as the walkway data collection file
 - f. At start of trial: begin with walkway data collection: press record button. Walk way will then auto start Vicon collecting data. (Walk way will start and stop automatically). When participant is off walkway mat stop Vicon.
 - g. Participant waits at other end of lab. For pathology patients ensure there is a seat for them to sit on.
 - h. Save the walkway file ensuring to enter the correct code in the diagnosis/procedure box
 - i. Disarm the Vicon trigger.
 - j. Change the file name to F for force plate.
 - k. Ask participant to begin walk.
 - l. Start Vicon ensuring that participant strikes the force plate (Via Baslar)
 - m. Stop Vicon at end.
 - n. Participant to stop and rest
 - o. Rearm the Vicon trigger signal
 - p. Change file name to W for walkway and repeat from point (f)
19. Run pipeline and check trials. Repeat as necessary. Play back pressure data and repeat as necessary.

12.10 Participant consent and information sheet.

Participant Information Sheet

1 Study title

The effect of Posterior Tibial Tendon Dysfunction (PTTD) on the biomechanical characteristics of the lower extremity (PTTD is a condition that can result in a painful flat foot).

2 Invitation paragraph

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Talk to others about the study if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3 What is the purpose of the study?

The proposed program of research will involve the investigation of the current forms of assessment, progression, and cause of PTTD. The research will aim to design and develop an accurate set of criteria for the early diagnosis of the pathology. The results will contribute to the development of new guidance for the classification of PTTD.

4 Why have I been invited?

You have been invited as you do not appear to have any foot deformity. The study requires people with no foot deformity to act as a control group. If you are assessed and do have a foot deformity, you will not be required to participate any further.

5 Do I have to take part?

It is up to you to decide. I will describe the study and go through this information sheet, which I will then give to you. I will then ask you to sign a consent form to show you have agreed to take part. You are free to withdraw at any time, without giving a reason.

6 What will happen to me if I take part?

If you decide to take part you will be required to attend the human movement laboratory at Staffordshire University for approximately two hours in order for you to have some measurements taken relating to your walking. This will involve having foot pressure sensors placed in your shoes. This will allow us to record foot pressures in your shoes while you walk. We will also be marking your foot and leg with small removable spherical markers. You will then be required to walk a few steps over a force plate embedded in the floor. This will allow us to collect information about the way that you walk.

Once you have had your walking assessment completed you will be sent an appointment to have a Magnetic Resonance Image (MRI) at University Hospital North Staffordshire. This appointment will be arranged by the researcher. MRI scans are routinely carried out for patients that have the particular foot condition being investigated in this study. Even though you do not have a foot condition, we still require you to have an MRI. This is necessary because we need to compare your results with those of people who do have the foot condition that we are studying (the experimental group).

7 What will I have to do?

There are no particular restrictions that we will ask you to observe should you choose to take part. If you do decide to take part it is important that you are able to attend your appointment for the time that it will take (approximately two hours) to collect all the information. If you are not able to attend the appointment arranged for you, we are more than happy to re-arrange it for you, so please get in touch if you think you do need to change your time slot.

8 What are the possible disadvantages and risks of taking part?

During this study instruments to measure movement during walking will be used. This requires the attachment of skin markers to your skin using medical tape. It is possible, although uncommon, that some people may develop a mild allergic reaction to this tape. If this happens I will remove the tape immediately. I will ask about possible allergies before starting the study and will give you advice about managing any such allergies should one develop after the data collection appointment.

If, whilst at your appointment, we discover that you have a foot condition we will provide you with details about how to obtain help to manage this condition. We will not be able to provide you with any treatment at the data collection appointment.

9 What are the possible benefits of taking part?

You will not benefit directly from taking part in this study but the information we get will help improve the understanding of the diagnosis and treatment of people with PTTD.

10 What if there is a problem?

In the unfortunate situation where you feel there is cause for complaint, there is a procedure in place to help you. Any complaint about the way you have been dealt with during the study or any possible harm you might have suffered can be addressed by contacting my supervisor. For contact details see the bottom of the information sheet. If you wish to make a formal complaint, the complaints procedure for the university will be adhered to, and I will advise you of where to obtain information about making a formal complaint.

11 Will my taking part in the study be kept confidential?

Your confidentiality will be safeguarded throughout the study, and beyond, should any publications arise from the study. All data will be coded, and individual names will not be used. This means that all data will be anonymous and non-identifiable. All data, including the signed consent forms, will be kept in a locked filing cabinet, and all electronic data will be securely stored on a password protected computer and backed up on a secure, password protected server. The data collected will contribute towards a larger study. As such, some of the data may be used as part of that larger study. This means that if the work is published, the data collected from the “stand alone” study that you may decide to take part in, might also contribute to another publication using combined data from more than one study. Access to the data will be restricted to the immediate supervision team involved in the project. Should the work be published the data will be made available to other professionals that have an interest in viewing the raw data. However all data will be non-identifiable data.

12 What will happen if I don't want to carry on with the study?

If you don't want to carry on with this study, you may withdraw at any time and without giving a reason

If this happens I may ask you whether you give permission to use the data I have collected up to the point of withdrawal. You retain the right to decide whether that data can be used.

13 What will happen to the results of the research study?

It is hoped that the results of the study will contribute to the understanding of this condition. Therefore it is the intention that the work resulting from this study will be published. If you would like a copy of any publication that may result, I will be happy to provide you with details of how to access a copy. Any publications that do result from the data gathered will be anonymous, unless I have made it expressly clear to you and you have given consent for you to be identified.

14 Who has reviewed the study?

The study has been reviewed by an independent peer review process and by the NHS local research ethics committee

15 Contacts for further information

Supervisors Contact Details:

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Thank you for considering taking part in this study.

Participant Information Sheet Experimental Group

1 Study title

The effect of Posterior Tibial Tendon Dysfunction (PTTD) on the biomechanical characteristics of the lower extremity (PTTD is a condition that can result in a painful flat foot).

2 Invitation paragraph

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Talk to others about the study if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3 What is the purpose of the study?

The proposed program of research will involve the investigation of the current forms of assessment, progression, and cause of PTTD. The research will aim to design and develop an accurate set of criteria for the early diagnosis of the pathology. The results will contribute to the development of new guidance for the classification of PTTD.

4 Why have I been invited?

You have been invited to participate because you have pain in your foot or feet in the area that matches the anatomical area where PTTD is present. Your consultant or clinician has provided this information sheet for you so that you can decide if you would like to take part.

5 Do I have to take part?

It is up to you to decide. I will describe the study and go through this information sheet, which I will then give to you. I will then ask you to sign a consent form to show you have agreed to take part. You are free to withdraw at any time, without giving a reason.

6 What will happen to me if I take part?

If you decide to take part you will be asked to attend the human movement laboratory at Staffordshire University for approximately two hours in order for you to have some measurements taken relating your walking. This will involve having foot pressure sensors placed in your shoes. These will be applied to anatomical locations on your foot and leg. This will allow us to record foot pressures in your shoes while you walk. We will also be marking your foot and leg with small removable spherical markers. You will then be required to walk a few steps over a force plate embedded in the floor. This will allow us to collect information about the way that you walk.

Once you have had your walking assessment completed you will be sent an appointment to have an Magnetic Resonance Image (MRI). This appointment will be arranged by the consultant in charge of your care. The MRI scan is routinely requested by your consultant in order to aid diagnosis of your foot condition.

In some cases your consultant may refer you for a surgical procedure to help treat your foot condition. Not all people need to have surgery. The decision about having surgery will be made by your consultant, and will be based on the severity of the condition. However, if your surgeon has already (?) put you on a waiting list for surgery, you will be invited to attend for further assessments after your surgery and once you are able to walk unaided. Your walking will be assessed again just as it was on the first occasion.. This will allow us to see whether your walking may have changed after surgery.

7 What will I have to do?

There are no particular restrictions that we will ask you to observe should you choose to take part. In addition to what has been explained above, we will ask you to complete a questionnaire which will provide us with information about how your foot pain interferes with your daily activities, and how it affects you on a day to day basis. You will be able to complete this questionnaire when you attend your first appointment. If you attend for a second appointment we will ask you to fill in the questionnaire again. This is to help us see what differences the surgical procedure has made to your quality of life after having the surgery. It is important that you are able to attend either one or both appointments if you do decide to take part. If you are not able to attend the appointment

arranged for you, we are more than happy to re-arrange it for you, so please get in touch if you think you do need to change your time slot.

8 What are the possible disadvantages and risks of taking part?

During this study instruments to measure movement during walking will be used. This requires the attachment of skin markers to your skin using medical tape. It is possible, although uncommon, that some people may develop a mild allergic reaction to this tape. If this happens I will remove the tape immediately. I will ask about possible allergies before starting the study and will give you advice about managing any such allergies should one develop after the data collection appointment.

If, whilst at your appointment, we discover that you have a foot condition other than the one that we are studying we will provide you with details about how to obtain help to manage this condition. We will not be able to provide you with any treatment at the data collection appointment, but will provide you with advice, and where to obtain professional help.

9 What are the possible benefits of taking part?

You will not benefit directly from taking part in this study but the information we get will help improve the understanding of the diagnosis and treatment of people with PTTD.

10 What if there is a problem?

In the unfortunate situation where you feel there is cause for complaint, there is a procedure in place to help you. Any complaint about the way you have been dealt with during the study or any possible harm you might have suffered can be addressed by contacting my supervisor. For contact details see the bottom of the information sheet. If you wish to make a formal complaint, the complaints procedure for the university will be adhered to, and I will advise you of where to obtain information about making a formal complaint.

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Student Contact Details:

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University of Brighton
School of Health Professions
49 Darley Road
Eastbourne
BN 20 7UR
01273 644598
b.durrant@brighton.ac.uk

Thank you for considering taking part in this study.

(Form to be on headed paper)

Centre Number:

Study Number:

Patient Identification Number for this trial:

CONSENT FORM

Title of Project:

The effect of Posterior Tibial Tendon Dysfunction (PTTD) on the biomechanical characteristics of the lower extremity.

Name of Researcher: Beverley Durrant

Please initial box

1. I confirm that I have read and understand the information sheet dated.....

(version.....) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected.

3. I understand that relevant sections of my medical notes and data collected during the study, may be looked at by individuals from Staffordshire University, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.

4. I agree to my GP being informed of my participation in the study

5. I agree to take part in the above study.

Name of Patient

Date

Signature

Name of Person

Date

Signature

taking consent

When completed, 1 for patient; 1 for researcher site file; 1 (original) to be kept in medical notes

(Form to be on headed paper)

Centre Number:

Study Number:

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CONSENT FORM

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